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EXPLOSION TESTS UNDER THICK POLAR ICE (U)

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1 NOVEMBER 1961

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UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND

NOLTR 61-146



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# EXPLOSION TESTS UNDER THICK POLAR ICE

Prepared by:
Donald M. Leslie
Carl A. Nelson

ABSTRACT: Several small charges of high explosive were fired under old polar ice in the Arctic Ocean to study their effects on ice. At the test site the ice varied from 8 feet to about 16 feet in thickness, and was characterized by low salinity, relatively warm temperature, and moderately high tensile strength. It was concluded that a 35-pound charge of HBX-3 exploded at optimum standoff distance beneath this type of ice will pulverize an area at least 40 feet in diameter, and will crack the ice extensively in an area about 90 feet in diameter

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NOLTR 61-146 1 November 1961

EXPLOSION TESTS UNDER THICK POLAR ICE

The tests reported herein were conducted under BuWeps Task RUME 2E-031, "Applied Research, Analysis and Planning," to provide more insight into the effects of explosions on ice and to provide specific data on which the development of a submarine under-ice surfacing device can be based. The study was necessarily limited to one variety of ice under summertime conditions in the Arctic. For the first time in this type of test an attempt was made to relate the effects data to the ice strength. The conclusions reached represent the current opinions of the Naval Ordnance Laboratory in this area.

The assistance of the Office of Naval Research, the Arctic Research Laboratory of the University of Alaska, the Icebreaker USS STATEN ISLAND AGB-5, and of Underwater Demolition Unit No. 1 (COMPHIBPAC) in conducting these tests is gratefully acknowledged.

W. D. COLEMAN
Captain, USN
Commander

L. C. Fisher

L. C. FISHER
By direction

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# Chapter 1

## INTRODUCTION

In response to interest in a device which would enable submarines traveling under thick polar ice to gain access to the surface quickly during an emergency, the Laboratory designed and furnished several experimental explosive ice destructors to the USS SARGO SS(N)583 and the USS SEADRAGON SS(N)584 for testing during their polar cruises in 1959 and 1960 (Project ICESKATE). Difficulties by both vessels in locating the opening produced by the destructors (see references (a) and (b)) forced the abandonment of this particular approach, at least temporarily. In the spring of 1961 interest shifted to a somewhat different approach to the under-ice emergency surfacing problem. Rather than use a large explosive charge which produces a substantial opening but requires the submarine to retire to a considerable distance during the explosion, it was now proposed to use a much smaller charge which cracks or pulverizes a small area of ice, in direct combination with the kinetic energy and buoyancy forces of the ascending submarine. Under this proposal, the explosive charge must be large enough to crack through the thickest ice normally encountered, but must be so small that it will not significantly damage the submarine when exploded a short distance overhead. Under this concept the small, buoyant charge would be launched from either the sail or a forward torpedo tube, and would rise to the lower surface of the ice. It would then be armed and fired remotely through an umbilical cable attached to the submarine. The submarine would then maneuver as necessary to be directly under the cracked area, hover at zero velocity relative to the ice canopy, and rise at a controlled rate so that the sail would impact the cracked or pulverized area and break through to the surface. SKATE-class Arctic submarines currently are capable of breaking through "thin" ice (up to about six feet thick) unaided. Thus, the assist device is needed only in "thick" ice (from six to about twelve feet thick). Other agencies are investigating non-explosive methods of egress through thick ice canopy, utilizing steam or water jets, mechanical and thermal devices, direct strengthening of the sail structure, etc.

A feasibility study of the small-charge concept was conducted by the Laboratory in the spring of 1961 (reference (c)), and the Laboratory concluded that this approach was feasible provided a "small" charge of about 60 pounds (or less) would produce the desired effect on sea ice, and provided the

submarine could perform the necessary maneuvers under emergency conditions. It was the prime purpose of the tests reported herein to explore by direct measurements the first provision, i.e., the size of charge necessary to crack through 12 feet of sea ice.

The information available on the effects of explosions underneath sea ice is very meager. Only four tests are known to have been conducted, all under NOL auspices. These are the scaled small-charge tests on lake ice (called the Moonshine Lake Tests, reference (d)); the simulation tests using very small charges under plaster board (to simulate the ice); the full-scale ICESKATE tests conducted from the USS STATEN ISLAND AGB-5 under thin seasonal ice in the Bering Sea in February 1960 (reference (e)); and the experimental ICESKATE shots by SARGO and SEADRAGON under thick ice (from which no data were obtained). The known data from these tests have been summarized and analyzed by R. Barash in reference (f). From these studies the Laboratory has attempted to scale or extrapolate the minimum charge size required to crack or pulverize 12 feet of sea ice in a 60-foot diameter area. It appears that this lies somewhere between 25 and 125 pounds of HBX-3, but, due to uncertain scaling factors, a more specific choice cannot be made with confidence.

By reference (g) the Laboratory proposed a general program of Arctic studies related to ICESKATE and to the Mine Program. The first specific test was a direct investigation of the effects of small charges exploded under thick sea ice. It was proposed that these tests be conducted by NOL, working from the Arctic Research Laboratory, Point Barrow, Alaska. ARL air support, or icebreaker (ship) support, was to be used to put the test party and gear on sea ice of the desired characteristics. ONR approval for the use of ARL facilities (operated by the University of Alaska under contract to ONR) was granted by reference (h). It was decided to run the initial tests during the summer of 1961, thus ruling out air support. By reference (i), ONR requested the necessary icebreaker services from CINCPAC for this and other scientific Arctic projects for 1961.

# Chapter 2

## OBJECTIVES

The specific objectives of this test thus may be stated as follows:

1. To obtain direct data on the effect of small charges exploded under thick sea ice, for the design of an ice destructor to meet SW-001102(REU) "Submarine Under-Ice Operational Requirement," and also to meet the requests made by COMSUBLANT in references (j) and (k).

2. To obtain as much data as possible to extend the general knowledge of under-ice explosion effects.

3. To obtain data to compare the effects of a 640-pound HBX-3 explosion on thick sea ice with the effects of this same charge on thin sea ice (STATEN ISLAND tests, February 1960); to obtain data on the effects of a 1300-pound HBX-3 explosion (i.e., the largest reasonable amount of explosive which can be designed into a buoyant device launched from "standard" torpedo tubes) on thick sea ice.

In collecting the above data it was desired to relate the explosion effects to the strength of the ice used for the tests. Thus, it was desired to collect as much data on ice characteristics as possible.

## Chapter 3

## DEVELOPMENT OF TEST PLAN AND TEST GEAR

In general concept, the test plan to accomplish these objectives was very straightforward. Small charges, selected in accordance with an orderly plan based on the thickness of ice at the test location, were to be placed under the ice at selected standoff distances, armed and detonated. The explosion and its after effects were to be observed visually and photographed. Ice corings at the test area were to be taken and analyzed in order to "tie down" the effects to the particular ice at the test site. After due consideration it was decided not to measure shock wave amplitudes because of the marginal value of such data and the substantial complications involved in operating this gear away from ship's power under difficult conditions on the ice. The overall concept was simple, but the development of a specific test plan, hardware, and instrumentation posed some problems. These will be discussed in succeeding paragraphs in this section.

### PLACEMENT OF CHARGES IN POSITION

During the ICESKATE tests from the STATEN ISLAND in the Bering Sea in 1960, it was planned that the charges be placed in position under the ice and away from the edge by UDT swimmers ("frogmen"). However, after a near-fatal accident occurred, this method was dropped and the charges were lowered directly through holes cut through the ice. After the charges were in position the holes were packed with loose ice and snow (which then refroze) and the charges were fired in this suspended position. For large charges, greater than about 300 pounds, this method is considered to be acceptable since the hole discontinuity is small with respect to the bubble diameter. However, this method was not considered acceptable for the small charge shots planned for this program. A method was needed which would place the charges in position away from the hole or edge effects. Because of the accident earlier in the Bering Sea it was preferable not to require extensive under-ice swimming by divers. A number of other schemes were considered, including those involving the use of:

- Miniature submarines or torpedoes
- Inverted buoyant tracked vehicles
- Natural water currents or relative ice drift
- Devices which "skate" laterally as they sink, then are made buoyant and rise vertically
- Long buoyant pipe

After due consideration the buoyant pipe scheme (suggested by V. G. Costley), coupled with the use of swimmers, finally was chosen as the primary plan. As a back-up plan, underwater swimmers alone were to be used. The more elaborate schemes were dropped for several reasons, primarily because reliable hardware was not readily available without a substantial development program, and because of uncertainty of precise location of the charge. (No small underwater locator was readily available capable of determining precise location at the necessary distances.)

The buoyant pipe plan is described in detail in the Test Plan, Appendix A. In brief, a hole is first cut through the ice floe and its opposite upper and lower sides are cut away so that pipe can be inserted at an angle of about 30° to the horizontal. The test charge with its buoyancy can (connected so that the charge will be suspended at the desired stand-off distance beneath the ice) is attached to a release device at the end of the first section of pipe. A separate lead weight nearly large enough to cancel out the net buoyancy of the charge/buoyancy can system also is attached to this release device. The first section of pipe, with the attached gear, is then inserted through the hole at a 30° angle. Additional 20-foot sections are attached and inserted until the desired linear distance is reached. The pipe (2-inch diameter heavy wall 6061T6 aluminum) is welded closed at each end so that each section is slightly buoyant in sea water. After the last section is inserted, the entire assembly rises to the underneath side of the ice. After the location of the charge is established the release device is operated remotely and the pipe is withdrawn. When the instrumentation is in place, the charge is then armed and fired remotely. The strength of the pipe in bending was investigated in some detail to establish that the necessary slight buoyancy at the end of a very long moment arm would not overstress the pipe. A simulated test program, carried out at NOLTF, Solomons, Maryland, using a torpedo barge with a well through the middle to simulate the hole through the ice, showed that the plan was feasible, Appendix C.

TEST CHARGES

The test plan required charges varying in size from two pounds to 1300 pounds. It was not practical to make up separate charges for each possible size which might be needed, nor was it desirable, for logistic reasons, to require handling of any large charges. Therefore, a plan was worked out by C. A. Nelson and V. G. Costley for charges to be made up in seven module sizes, Appendix D. The largest of these was 200 pounds, which is small enough to be "manhandled" on the ice, and to be carried easily by light aircraft, if necessary. A total of 33 units in these seven module sizes was fabricated by the NOL shops and

loaded with HBX-3 at NWP, Yorktown, Virginia. From these 33 units charges in any desired total weight could be bolted together quickly on the ice at the test site. Explosive tests were conducted at NOL with the smaller units to establish that the shock wave transmitted from the arming device booster to the first unit was sufficient to initiate high-order detonation. In practice, this module plan worked very well, with no significant problems. A minor problem arose in explosive-loading the larger units at Yorktown, and if this scheme is used again side loading holes are to be preferred rather than center holes.

BUOYANCY CHAMBERS

For reasons of economy it was, at first, planned to use automobile tire "inner tubes" as buoyancy chambers to support the charges. It was quickly realized, however, that flexible containers of this type are vertically unstable when used fully submerged in near-neutral-buoyancy systems, and this approach was dropped. Standard shipping cans were then chosen for the purpose. Pressure tests on the larger containers showed that they would withstand about 50 feet of water before collapsing. Since the largest charge may have to be placed 150 feet away from the hole and thus (at a 30° angle), may reach a depth of 75 feet during placement, a few of the larger containers were equipped with internal fiber stiffeners. For shipping economy many of the containers were packed with other gear during shipment.

ARMING DEVICE

Perhaps the most common method of firing test charges remotely is to use an electric detonator inserted in, or attached directly to, the high explosive charge. Although this crude method has the authority of many years' usage behind it, it represents obsolete safety practices. Furthermore, the state of the art in "S and A" has advanced greatly in recent years. For these explosive tests in the Arctic under adverse conditions the test group preferred something safer. Consequently a motor-driven, remote-controlled arming device was adapted for these tests by W. Burke from his earlier ICESKATE arming device. A general arrangement sketch is attached for information as Appendix E. Basically the device consists of an electric detonator mounted in an Explosive Fitting, a Tetryl lead mounted in a rotating shutter, and a Tetryl booster. The shutter is driven by an electric motor through a reduction gear from the unaligned (safe) position to the aligned (armed) position, or vice versa. Switches actuated by the shutter electrically arm the primer circuit and disconnect the motor when the shutter has reached the "armed" position. The system is arranged so that the circuit can be monitored for "armed" or "disarmed" condition, the primer bridge wire resistance can be monitored, and the system can be disarmed remotely if the operator chooses

not to fire. Twelve models were made by the NOL shops. Two of these were expended in explosive tests to insure that the firing train (which is basically the same as that used on certain other arming devices) would fire properly, and would detonate the main charge. Five-conductor cable is used with this device.

# Chapter 4

## INSTRUMENTATION

Instrumentation of three types was planned: cameras for photographic coverage of the explosions and their effects; instruments for taking ice cores and measuring the ice characteristics; and linear (tape) measures for direct dimensional measurements. These are described below:

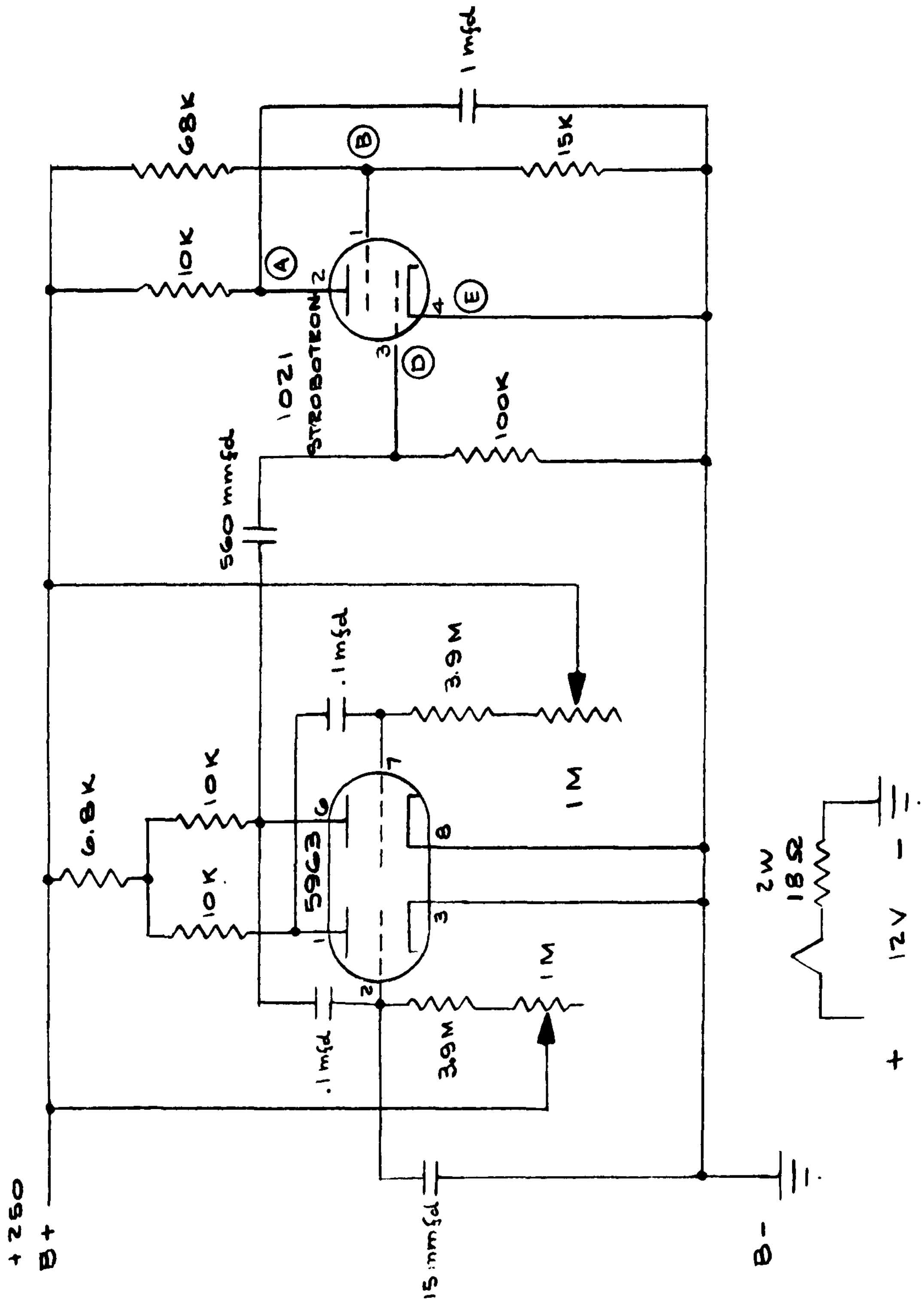
### PHOTOGRAPHIC

Two 16 mm. ground movie cameras were to be used as shown in Appendix B. One of these was to be operated at 64 frames/sec and the other at 16 frames/sec as a back-up. A third camera operating at 16 frames/sec was to be used from a helicopter hovering the same distance away and on the same bearing, but at an angle of about 30° with the vertical through ground zero. Two additional cameras were carried along for possible back-up use on the ground. All cameras were equipped with 35 mm.-focal-length lenses, which give a horizontal coverage on 16 mm. film of about 40 $\sqrt[3]{W}$ feet when used at the selected distances. For reference purposes two scale markers, assembled by the ship to NOL sketches, were to be used, Appendix B. These markers were to be placed about 30 $\sqrt[3]{W}$ feet apart, equally spaced on each side of ground zero. All cameras were "gun sight" cameras, equipped with internal heaters. They were loaded with 50-foot Kodachrome film magazines. Since their speed could not be controlled precisely, a strobe light system using a gas tube flashing once per second was made up by D. Torpy, J. Dempsey, and T. Heathcote to provide a time reference on the film, figure 1. Ground cameras were to be driven by lead-acid storage batteries loaned by the ship. The helicopter camera was to be operated off the helicopter main battery. Some degree of still-camera coverage was to be provided by a Speed-Graphic camera operated by one of the ship's photographers, and by 35 mm. cameras and a Polaroid-Land camera, operated, when time permitted, by members of the test party.

### ICE DATA

Ice cores were to be taken with a SIPRE (now CRREL) coring auger (manufactured by the General Mechanical Co., Chicago, Illinois). Temperatures of these 3-inch diameter cores were to be taken at about 2-foot intervals immediately after removal, using Taylor bi-metallic thermometers temporarily bound to the cores with a wad of insulating material. Three-inch sections were then to be sawed out of the cores at intervals, using a miter box made for the purpose. These sections were then to be

**Fig. 1 Circuit of Strobe Light for Cameras**




Frequency varies 4% with change of voltage from 9 to 13 volts.

drilled through the cylindrical axis with a 1/2-inch drill held in a special jig. The resulting test sections were to be weighed to the nearest gram and then put on the mechanical press made by Soiltest, Inc., modified as suggested by Dr. Assur of CRREL, for unconfined compression tests. Under this procedure (reference (b)) the sample is subjected to a compressive force by the press, which creates a tensile stress in the sample, causing failure at one point in tension. The force necessary to split the sample is recorded from the ring gage and from this the tensile strength of the ice is computed. Samples of the cores also were to be taken back to ARL in sample bottles, where standard titration tests could be run to determine salinity. For all the ice measurements, the NOL test party was fortunate in having the assistance of Mr. Chia-Yao Yuan, presently working at ARL with Dr. Hal Peyton of the University of Alaska. Mr. Yuan's knowledge and experience in ice measurements proved to be invaluable to the NOL test party.

LINEAL MEASUREMENTS

Among the most important data obtained from these tests were the direct observations of dimensions of the cracked or pulverized areas resulting from the explosions. Reference marker and camera positions were to be laid off by tape measure. It was intended to take similar direct measurements of the affected ice areas. This was not feasible in most cases, however, due to the fact that shots were necessarily made near the ice edge (some 150 feet in) and large portions of the floe cracked off and began to drift away immediately after each shot, particularly #1 and #2. Thus, the area diameters were estimated visually based on the known separation of the reference markers. These estimates were confirmed or corrected, where necessary, by post analysis of the movie film.

## Chapter 5

## PRELIMINARY PLANNING TRIP

In order to confirm preliminary plans and work out remaining details on this somewhat unorthodox test, an advance planning trip was made by C. C. Vogt and D. M. Leslie of NOL several weeks before the scheduled tests. Brief visits were made to LCdr. Boyington, Underwater Demolition Unit #1 (San Diego); Dr. W. K. Lyon, the "father of submarine polar travel," at NEL (San Diego); Cdr. W. L. Larsen, USS STATEN ISLAND (Seattle); Capt. C. D. Huston and Capt. Strickler, COMALSEAFRON (Kodiak); Dr. C. T. Elvey, University of Alaska (Fairbanks); and Mr. Max Brewer, Director of the Arctic Research Laboratory (Point Barrow). During this trip the final plans were worked out and agreed upon. STATEN ISLAND planned to arrive at Point Barrow about 17 August and leave shortly afterwards to provide heavy logistic support to ARLIS-II. It was originally planned that the NOL group would be embarked on this trip and would conduct the explosion test program sometime during the trip, probably after visiting ARLIS-II. (However, this plan was later changed to embark the NOL group on a later trip after the ship's visit to ARLIS-II.) The bulk of the NOL test gear, including the explosive charges, had been shipped to Seattle in time to go up on the STATEN ISLAND. A small amount of instruments and late test gear was air-shipped directly to ARL. Due to a last-minute change in ship schedule, brought about by ice damage to the USS BURTON ISLAND near Barrow, the test date was moved up from September to late August.

# Chapter 6

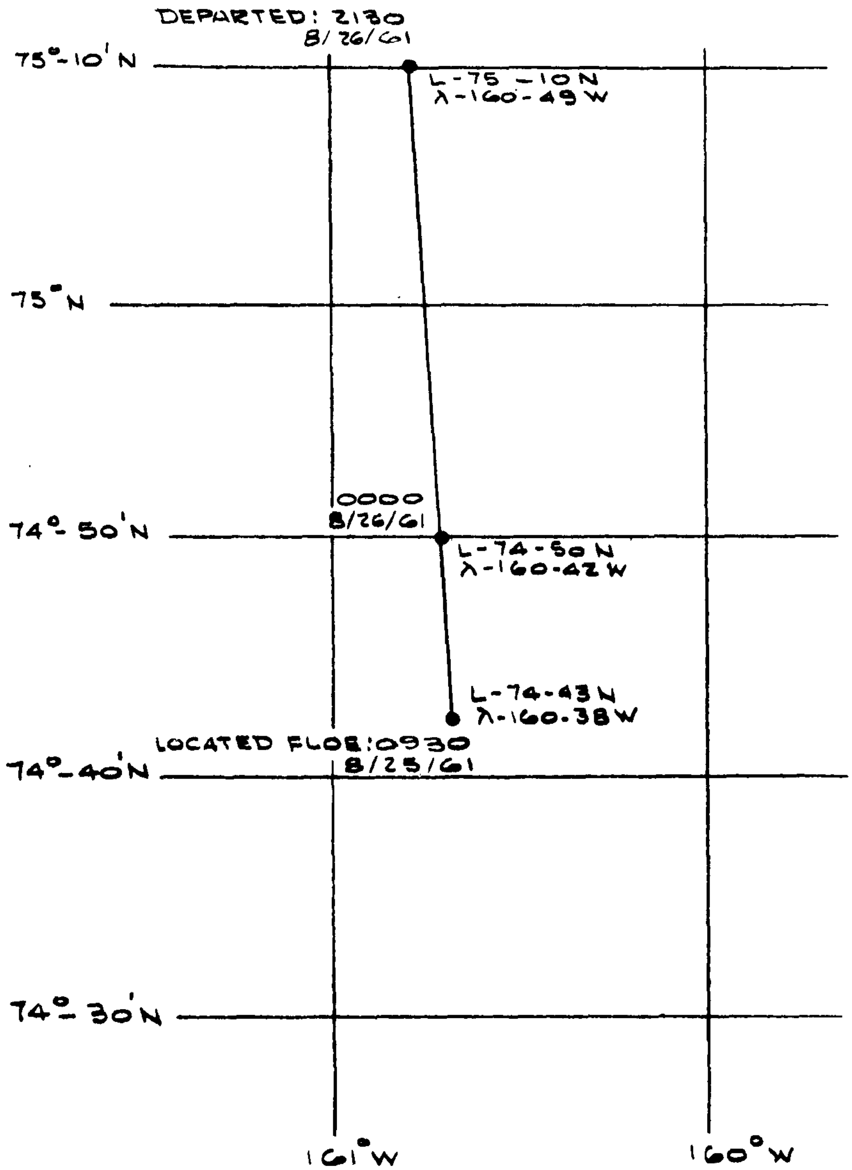
## TESTS AND RESULTS

The NOL test party arrived at Point Barrow on 17 and 18 August. On 18 August the STATEN ISLAND left for ARLIS-II and Fletcher's Ice Island. As mentioned previously the NOL test party was not embarked on this trip, although the test party chief did ride the ship as an ice observer. On 22 August the STATEN ISLAND left Point Barrow with the NOL test party and other scientific projects aboard.

On 24 August the STATEN ISLAND was released from other projects for the NOL under-ice explosion tests. At this time she was about 180 miles northwest of Point Barrow. The ice pack was in a rather disintegrated condition with six-to nine-tenths coverage, and the ship was able to move with considerable freedom, with only moderate effect on speed. No suitable ice had been observed for the NOL tests thus far. Following the earlier suggestions of Dr. Lyon and others, the ship now turned northwestward toward the Beaufort Sea, since this course seemed to promise the greatest probability of encountering old polar ice. In addition to the normal observations from the bridge, a special lookout, consisting of the members of the NOL test party, the officer-in-charge of the Underwater Demolition Team, and Mr. Chia-Yao Yuan, in rotation, was posted in the crow's-nest. As noted earlier in this report, thick sea ice was essential for these tests. In a single winter season around the fringes of the Arctic Ocean pack ice grows to a thickness no greater than six feet, and this seasonal ice largely melts or disintegrates during the following summer. Nearer the cold pole, however, the ice does not entirely disintegrate during the summer (ARLIS-II lost 5-1/2 feet in thickness due to surface melting during the past summer), and during succeeding winters more growth is added (at the bottom surface). If it were not for the irregular outward drift of ice, and the inherent thermal insulating effect of the ice, this process would continue indefinitely. As a practical matter, however, flat sea ice (i.e., not rafted or pressure ridged) seems to be limited in the Arctic basin to about 12 feet in thickness. This thicker sea ice is called "old polar ice" and is generally characterized by low salinity, an irregular, greyish, hummocked surface, and (by transmittal light along the edges or in holes) a pure blue color.

In less than one day's search a large floe of old polar ice was found at Lat. 74°43' N, 160°38' W, 25 August 1961

**Fig. 2 Plot of Location of Freeman's Ice Floe During NOL Tests**



(fig. 2). This was dubbed "Freeman's Ice Floe" since it was first observed by Lt(jg) C. Freeman, Officer-in-Charge of the Underwater Demolition Team, while on lookout in the crow's-nest. Judging from experience of the past week, and from pessimistic predictions by various ice experts, this discovery must be considered nothing short of fortuitous. Other than ARLIS-II and T-3 (both of which are glacial ice), no large contiguous areas of ice had been seen previously on this expedition, and only a few isolated small fragments of (thick) old polar ice had been observed. Freeman's Ice Floe was judged to be true sea ice, and not glacial ice, because it was somewhat saline (though salinity was rather low), and because no glacial moraine was observed at any time during the occupancy of the floe. The surface of the floe was quite irregular, and was covered almost entirely with small hummocks and melt pools. The hummocks ranged up to three or four feet in height. The melt pools were green in color and of irregular shape and size, varying from about three or four feet to some thirty feet in minimum dimension. The fall season already having started, these pools were covered by a film of ice one to two inches thick. This surface film usually was strong enough to support a man if he walked carefully. Underneath the surface ice there was a layer of melt water 8 to 18 inches thick above the underlying floe ice. At the thinnest point observed, the floe was six feet thick (this was at the edge). From later observations it was found that maximum thickness was at least 20 feet. Due to the irregular nature of the surface, the thickness of any selected test site must be recognized only as a nominal value. Pressure ridges were found at intervals, reaching a height of about 15 feet. Similarly, refrozen "cracks" resembling the melt pools were sometimes observed. Helicopter observations showed that the floe was large, roughly circular, with a diameter of about 1-1/4 miles. Water depth at this point was 950 fathoms, far more than the necessary minimum.

A test core confirmed the nature of the ice. The first test core was drilled to 15 feet without breaking through (fig. 3). Test party and test gear were put ashore immediately. The test party was organized functionally as follows:

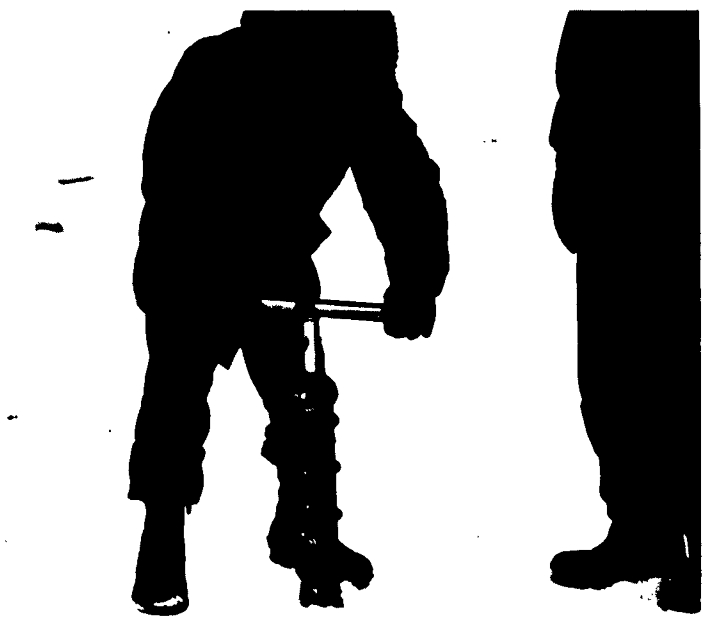


FIG. 3 OBTAINING A SAMPLE ICE CORE

| | Preparation Phase | Place Charges in Position | Firing |
|---|---|---|---|
| Assemble Arming Device, run cable, check out firing system | Burke Gulledge | | |
| Assemble Charge System with AD, buoyancy cans | Nelson Burke Gulledge | | |
| Place Charges in position under the ice | | Nelson Gulledge UDT Team | |
| Set up cameras and markers, operate cameras | Heathcote | | Heathcote Ship's Photo. Mate in Helicopter |
| Take ice cores, measure characteristics of samples | Axtell Yuan | Axtell Yuan | Axtell Yuan |
| Cut, dig, or blast access holes through ice | Lt(jg)Chidsey and Ship's Working Party | Lt(jg)Chidsey and Ship's Working Party | Lt(jg)Chidsey and Ship's Working Party |
| Liaison with Ship, overall charge | Leslie | Leslie | Leslie |

A site was selected and, in accordance with the plan (Appendices A and B) a working party from the ship began efforts to get a 4 ft. x 6 ft. hole through the ice for the first shot. A chain saw, with pickaxes and ice chisels, was used. After a depression some four or five feet deep had been cut out, water began to seep through from a nearby melt pool. Shovels and buckets were used to bail the hole clear, temporarily. However, seepage continued to come through so a gasoline-driven fire pump was brought ashore. The motor apparently was defective and was never started, in spite of lengthy efforts. A small explosive charge was fired in the hole but with very little effect. Finally a decision was reached, after consultation with Cdr. Larson and Lt(jg) Freeman, to abandon the hole efforts temporarily and try to put the charges in position from the ice edge, using the buoyant pipe scheme, operating from one of the

ship's LCVP's. This plan was used for the first charge, with two divers "riding" the forward end of the pipe under the ice. A 60-pound charge was selected to match the estimated average of 12-foot thick ice in accordance with the test plan. The standoff distance beneath the ice ($\sqrt[3]{W}$ ft.) was 3.9 feet. A preliminary check had suggested that no significant current was present. However, this was later found to be wrong and considerable difficulty was experienced with the relative current during the placement of the pipe and the charge actually drifted a considerable distance out of position. Efforts by the divers were only partly successful in getting the charge back. Thus, the first charge was exploded considerably closer to the edge than desired. Because of this, and even more because of the lateness of the hour, the first shot was fired without helicopter photo coverage.

The conditions and results of the first shot are shown diagrammatically in figures 4 and 5. Because of the proximity to the ice edge a large area some 100 feet in diameter was scalloped out of the floe. Cleavage lines developed in the vicinity and substantial pieces of the floe began drifting away immediately. The nearness of the ice edge undoubtedly was a significant factor in the formation of these deep cracks; however, it did not appear to the test party that the pulverization effects of the explosion were affected by this factor. Because of the relatively large plume and large pulverized area, this 60-pound shot was considered somewhat oversize for the job desired. Therefore, a size of 35 pounds (one step down on the logarithmic scale, Appendix A), was chosen for the next shot in the same vicinity.

During discussions that night after the first shot, it was decided not to use the buoyant pipe scheme operating from a boat, as it had been decided to do when a hole could not be obtained. The extreme clarity of the water, coupled with good light transmission through the ice, made it feasible for the UDT swimmers to operate at reasonable distances under the ice. This was quite in contrast to the earlier STATEN ISLAND tests in the Bering Sea where darkness and murky water made it very difficult for divers to "navigate" under the ice. Thus it was decided to use divers alone to place succeeding small charges in position. At the same time it was decided that a ship's working party was to resume its efforts--in another area--to get a hole through the ice for the large charge tests.

During the evening after the first shot had been fired the wind shifted and there were indications that the ice pack might be blown against the ship. This aroused considerable concern on the part of the ship's captain, who decided that we could not stay at Freeman's Floe for the scheduled four days

## Conditions for Shot #1

**Charge:** 60 lbs. HBX-3 made up from two 30 lb. modules.

**Buoyancy and weights:** 3 float cans, 16 lb. lead weight.

**Standoff:** 47" beneath the ice.

**Time:** 2000 Z, 8/25/61

**Ice thickness:** 6' minimum, about 14' maximum.

**Placement:** By pipe method, with assistance of divers. Release at end of pipe operated prematurely.

**Firing conditions:** 24 volts lead-acid battery, at 450 ft. from ground zero.

**Cameras:** #1 (ground) f5.6 at 64 fps; #2 (ground) f5.6 at 16 fps, heaters not in operation, Ektachrome film.

## Test Layout at Time of Firing

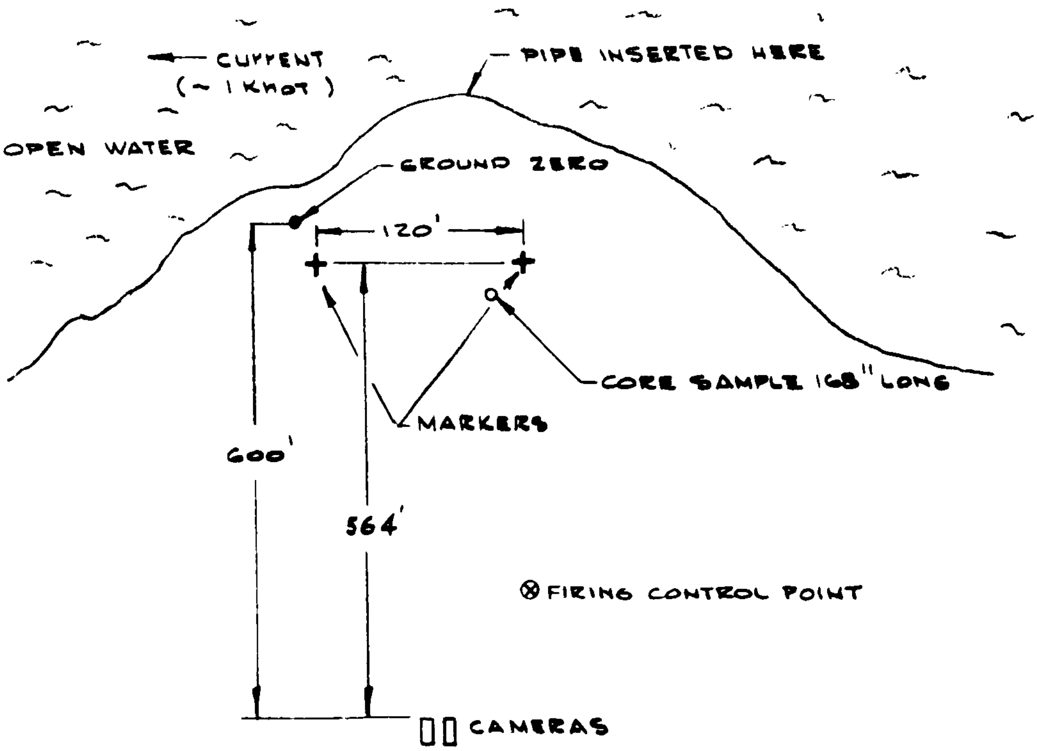



Fig.4 Shot #1

**Results of Shot #1**

**Diameter of pulverized area: greater than 100 feet**

**Ice coverage: 50%. Two large fragments about 4' x 6' in area. Rest, well pulverized.**

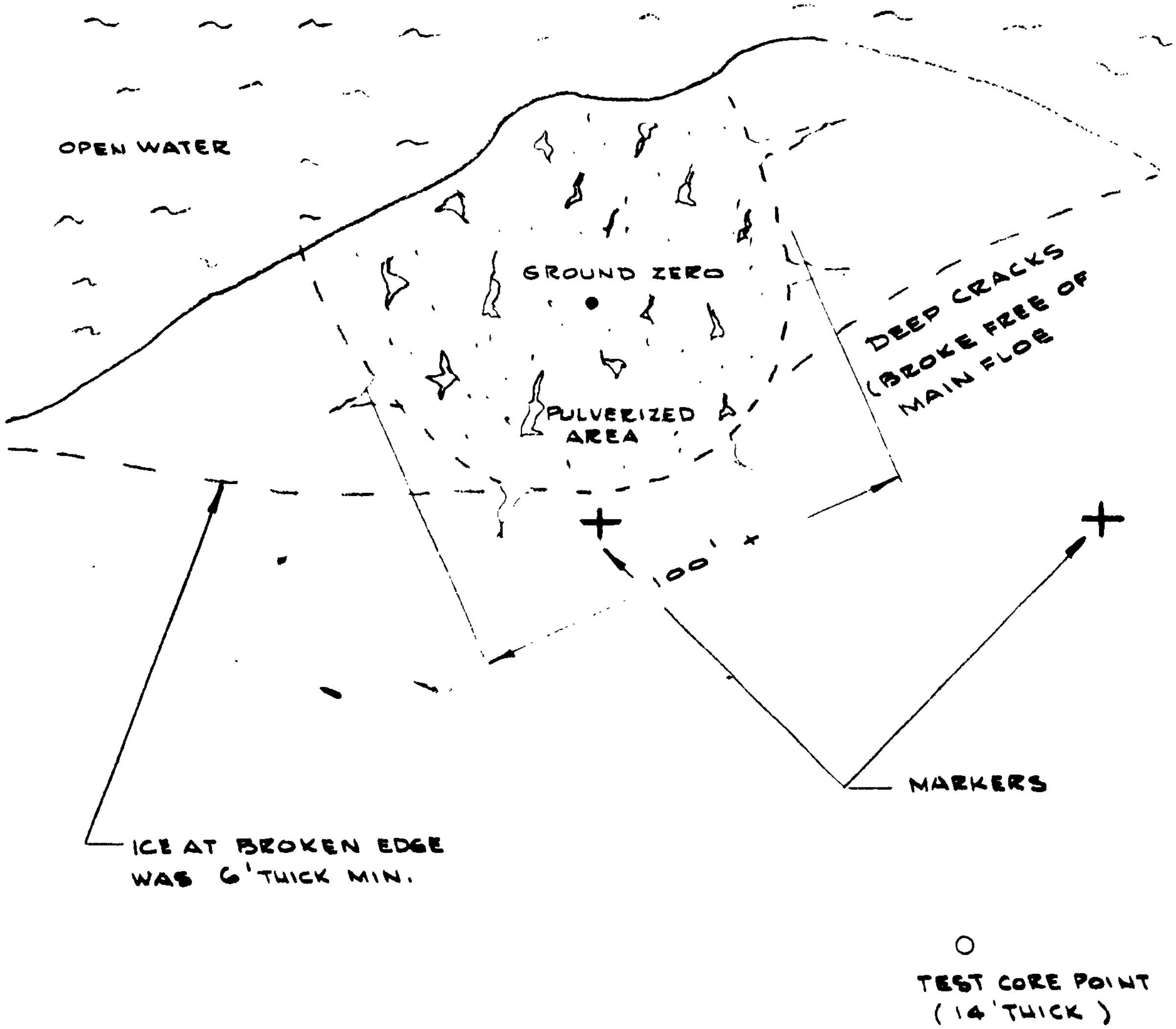



Fig. 5 Shot #1 (Cont'd)

of tests, but must leave by the following (Saturday) night or Sunday morning. As a consequence of this decision the tests had to be speeded up as much as possible. After spending several months preparing for the tests, however, this was a rather hard blow to the test party. In all fairness, however, it should be recognized that the ship's concern over safety was not without justification. Only a few weeks earlier the USS BURTON ISLAND (a sister icebreaker) had been caught by a similar shift in wind in this same general area and had suffered a jammed rudder from the ice pack. The BURTON ISLAND had to retire from the ice pack and abort her mission because of this damage. The net effect of this change of plans was to limit us to 1-1/2 days at the test site rather than 4 days as scheduled. (Actually, ONR had requested 15 days of icebreaker time at the test site for these tests, reference (i).)

The 35-pound charge for shot #2 was carried under the ice by the UDT swimmers (fig. 6) and attached to a section of pipe which had been inserted through a test core hole. This now became "ground zero." The standoff distance beneath the ice was 3.2 feet. The swimmers conducted this phase very quickly, without incident, requiring only four or five minutes to take the charge in and then come back out. The charge was armed and fired normally (fig. 7). For this shot, and shot #3, the countdown and firing signals were given from the ship's bridge, by radio. These signals were received at the test site by "walkie-talkie" and in the helicopter by a normal radio channel. At five seconds before firing the cameras were started. Firing was accomplished from the arming point on hand signal from the walkie-talkie operator. The conditions and results of this shot are shown in figures 8 and 9. Once again, large pieces of the floe cracked away and began to drift out to sea. A visual inspection of the area, together with a later analysis of the helicopter movies, indicated that a pulverized area about 40 feet in diameter and a thoroughly cracked area about 90 feet in diameter were produced (fig. 10). There was relatively slight venting of the bubble to the atmosphere. It was concluded that this charge was nearly optimum in size for the effects desired. At "ground zero" the ice was 14 feet thick. The divers reported that this point was about midway up on the slope of a "cathedral ceiling" on the underneath side of the ice, with the apex of the ceiling being about four feet higher. With a reasonably flat upper surface in the area the minimum thickness thus was about 10 feet, and the maximum was something greater than 14 feet.

For the third shot a different area was selected. A test core hole was put down to 17 feet (the maximum possible with the corer extensions available) without breaking through the ice. Not wishing to abandon the efforts so far, and in the

FIG. 6 UDT SWIMMERS PREPARING TO PLACE CHARGE UNDER THE ICE

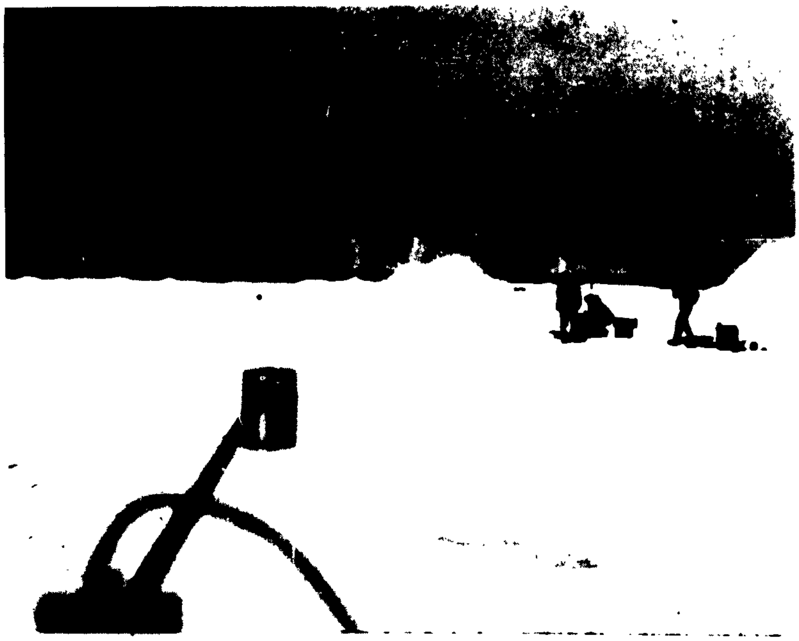


FIG.7 FIRING SHOT NO. 2 (35 LBS HBX-3)

## Conditions for Shot #2

**Charge:** 35 lbs. HBX-3 made up of one 30-lb. and one 5-lb. modules.

**Buoyancy and weights:** 2 buoyancy cans, 28 lbs. in lead weights.

**Standoff:** 40" beneath the ice.

**Time:** 1000 Z, 8/26/61

**Ice thickness:** 14 ft. at ground zero, varied elsewhere 10 ft. to 16 ft.

**Placement:** by UDT swimmers.

**Firing conditions:** 24 volts (four hot-shots) at 350 ft. from ground zero.

**Cameras:** #1 (ground) f4.0 at 64 fps; #2 (ground) f8.0 at 16 fps; #3 (in helicopter) f5.6 at 16 fps. Kodachrome in #1, #2; Ektachrome in #3.

## Test Layout at Time of Firing

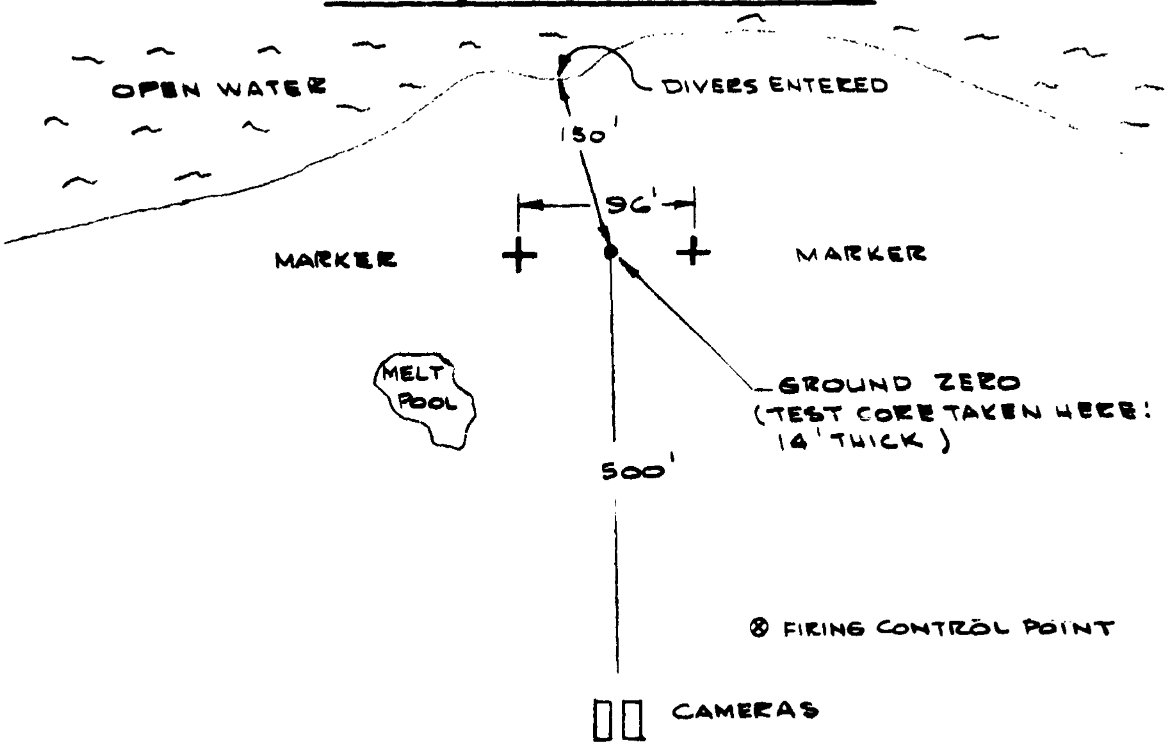



Fig. 8 Shot #2

**Results of Shot #2**

**Diameter of pulverized area:** 40', 75% ice filled (some open water in center), largest fragments 2' x 2'.

**Diameter of thoroughly cracked area:** 90'

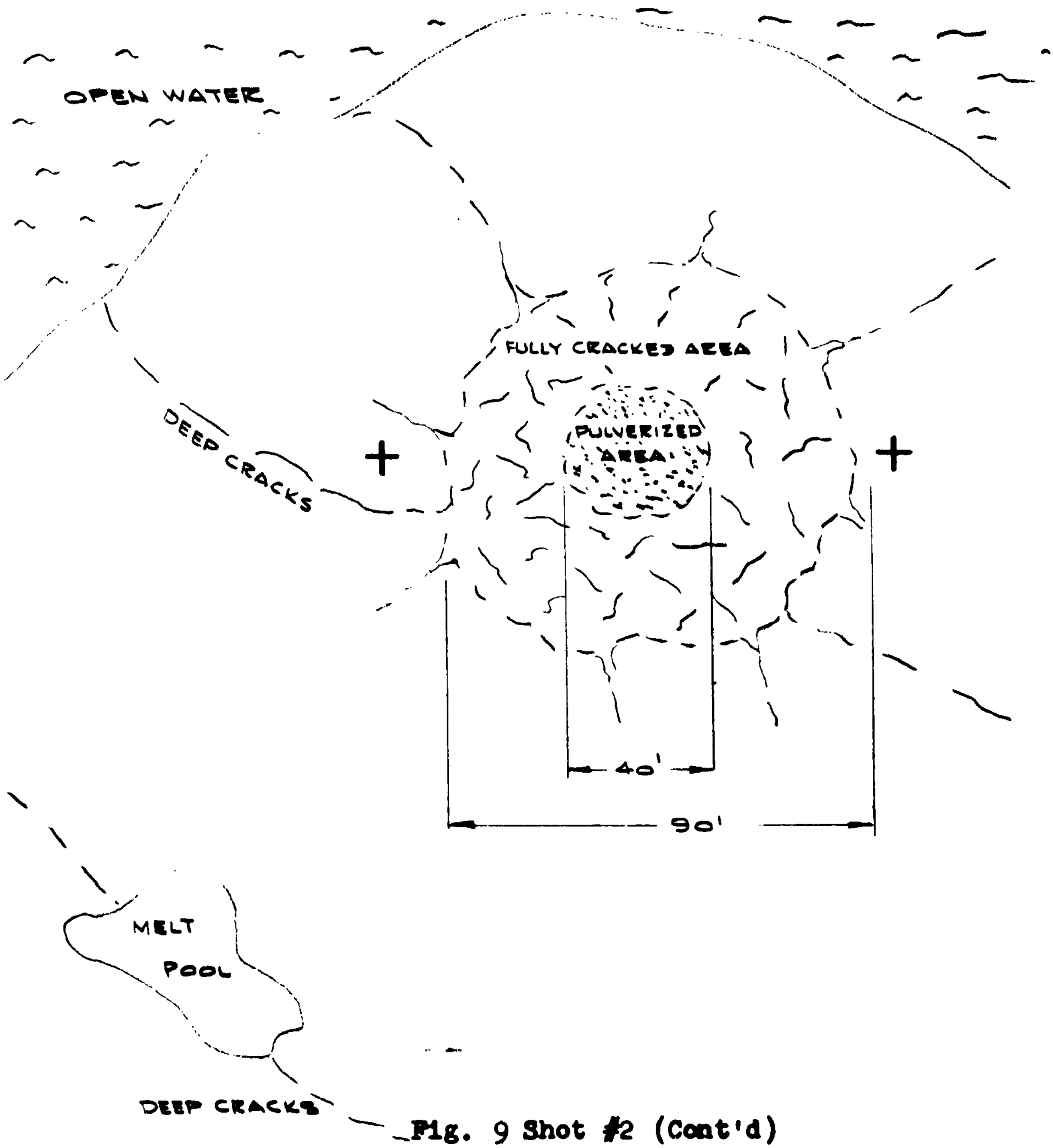



Fig. 9 Shot #2 (Cont'd)

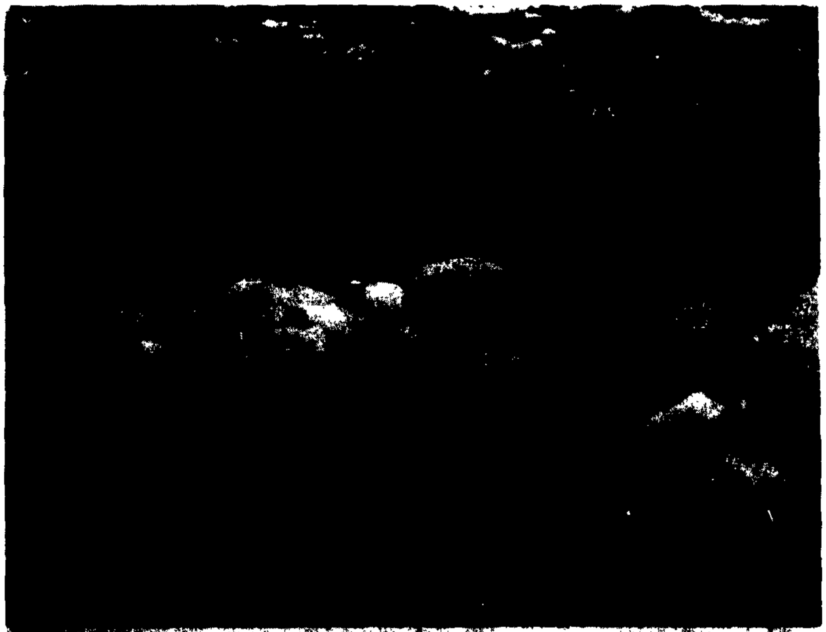


FIG. 10 PULVERIZED ICE FROM SHOT NO. 2

expectation that the ice would not be much thicker, a 20-foot section of pipe was placed in the hole and the sailors took turns driving this down with a sledge hammer. After some 1-1/2 hours effort the top of the pipe was flush with the ice and the pipe still was not through the ice. Reluctantly, then, this site was abandoned and a new area chosen. At the new location the ice was 9 feet 4 inches thick at "ground zero." Since the first shot was oversize and the second about optimum, it was decided that the most useful information could be obtained by "bracketing the target" and going down still further on the charge size. A 20-pound charge was selected (fig. 11). Again it was placed in position by the swimmers without difficulty, being attached to a pipe at "ground zero" with a standoff distance of 2.7 feet. Due to an unexplained misunderstanding the countdown was started by the bridge early, before the arming process was fully completed. Consequently, most of the film had been run off in the high-speed camera before the explosion. The conditions and results of shot #3 are shown in detail in figures 12 and 13. In general this was considered an undersize charge. Very slight venting occurred. No pulverization occurred but a mass of jumbled, turned chunks was produced in an area about 10 feet in diameter. Extensive cracking occurred out to about 100 feet diameter. Except for one or two isolated cracks, no further cracking was observed at greater distances.

Considering the short time available at the test site, and the fact that the three small shots had bracketed the desired size, it was decided to use the remaining hours in testing one or more of the large charges. It was planned, also, to coordinate these large explosions with seismic listening posts on ARLIS-II and at ARL, to provide additional data for this study of the earth's crust. In parallel with shots #2 and #3, a ship's working party had been trying to make a hole through the ice large enough to accept the 200-pound module, i.e., at least 30 inches clear diameter. This work was proceeding in another part of the floe, well "inland" of the other tests. Five standard M3 (40-pound) shaped charges and several small demolition charges of five pounds or less (Comp "C" and TNT) were used. The shaped charge produced a clean hole all the way through the ice (which appeared to be eight or nine feet thick at this location). This hole was about three feet in diameter at the upper surface, but funneled down to some six inches in diameter at the lower surface. Sea water, of course, immediately filled the hole up to a foot or so from the top surface, along with ice debris. Efforts to use an additional shaped charge nearby to enlarge the original hole resulted in one larger hole at the top surface but two small (6-inch) holes at the bottom surface. Other shaped charges failed to break out the bridge between the holes. Regular charges up to five

FIG. 11 ASSEMBLING SHOT NO. 3 (20 LBS HBX-3)

## Conditions for Shot #3

**Charge:** 20 lbs. HBX-3 made up from two 10-lb. modules.

**Buoyancy and weights:** 2 Mk 17 Floats, with 23 lbs. lead weight.

**Standoff:** 32" beneath the ice.

**Time:** 1500 Z, 8/26/61.

**Ice thickness:** 112" at ground zero.

**Placement:** by UDT swimmers.

**Firing conditions:** 24 volts (four hot-shots) at 450 ft. from ground zero.

**Cameras:** #1 (ground) f5.6 at 64 fps; #2 (ground) f11 at 16 fps; #3 (helicopter) f5.6 at 16 fps. Kodachrome in #1, #2; Ektachrome in #3.

## Test Layout at Time of Firing

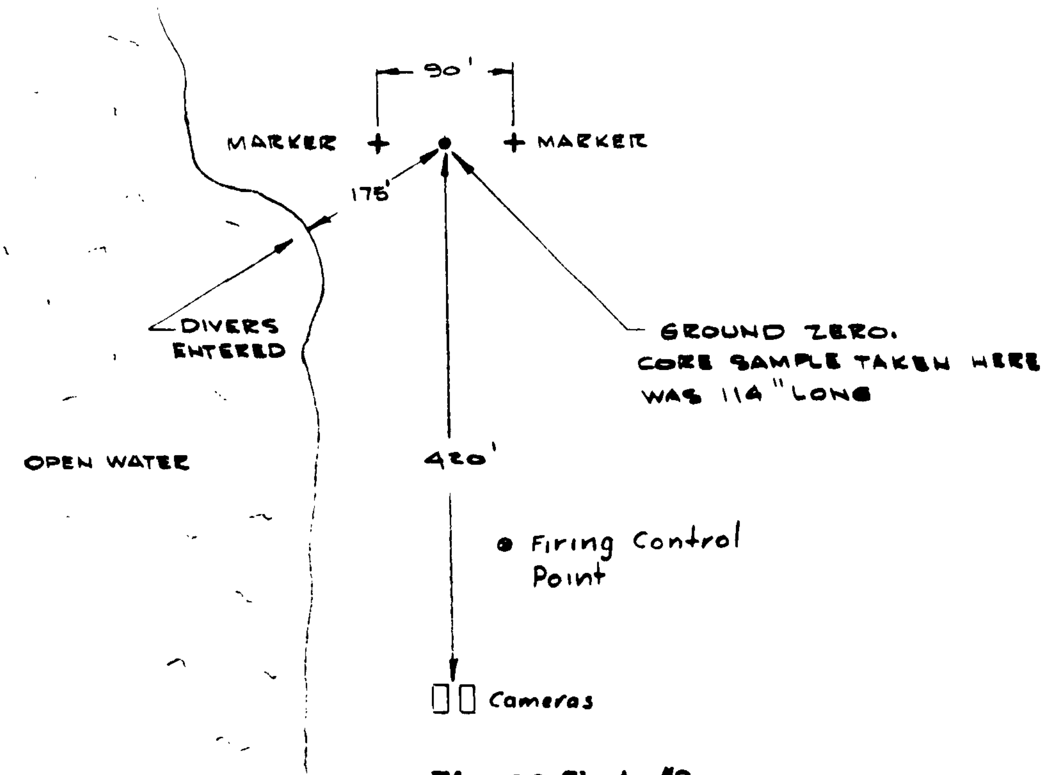



Fig. 12 Shot #3

Results of Shot #3

Diameter of pulverized area: none

Diameter of thoroughly cracked and jumbled area: about 15 ft.

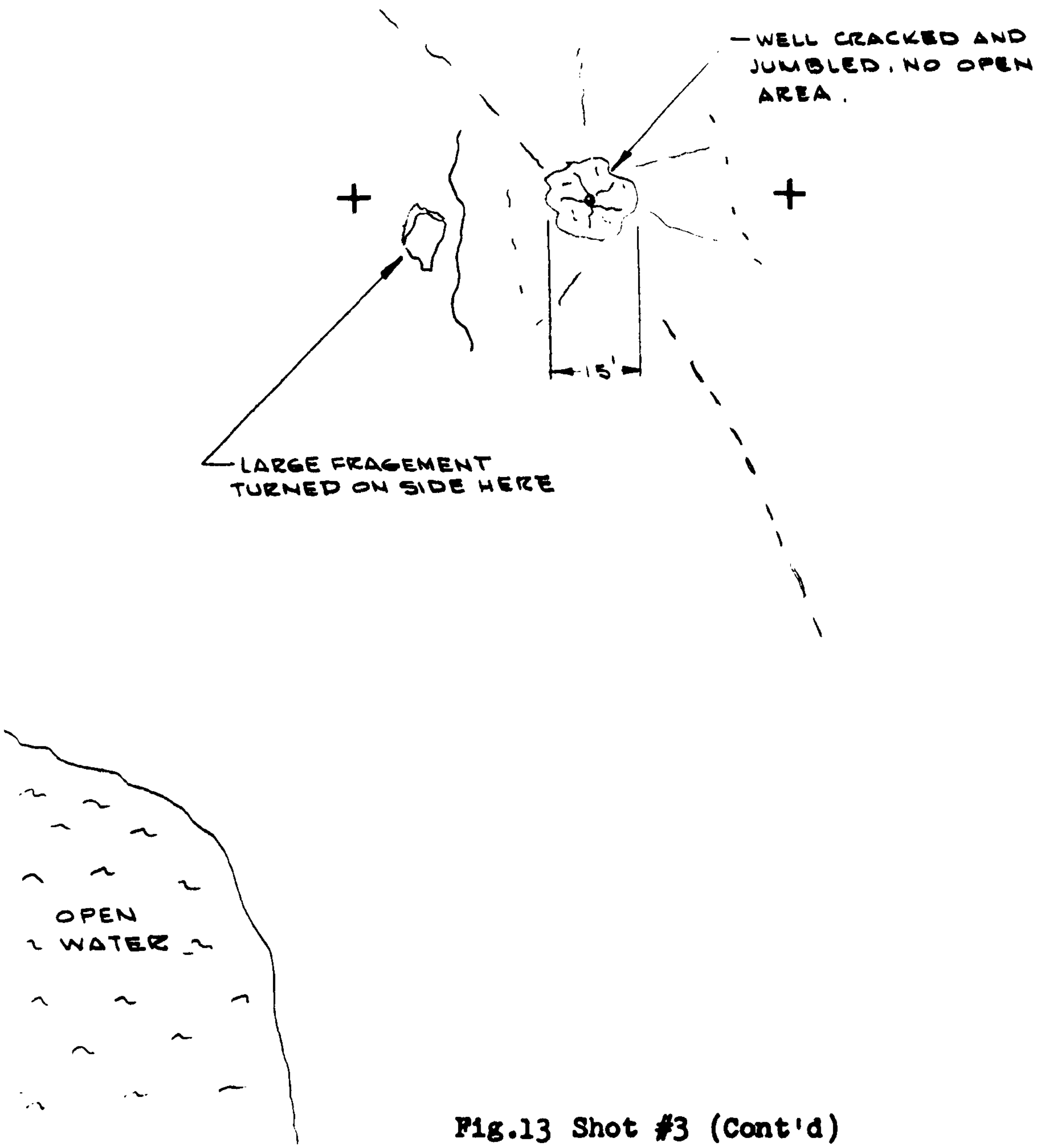



Fig.13 Shot #3 (Cont'd)

pounds of TNT (exploded in one of the bottom holes) merely produced a larger upper hole and more ice debris. It was thought imprudent to use larger charges which would probably produce cracks in the ice. During these efforts by the ship's working party, the NOL test team had set up cameras, assembled and checked out a new arming device, and offloaded modules from which to assemble the 630-pound charge. (The charges themselves could not be assembled until they were in position at the test site.) After about eight hours' effort by the ship's working party had failed to produce a suitable hole, and the hour (Saturday evening) was advancing, a conference was held to decide on a course of action. The UDT swimmers offered to swim the large charge in position under the ice, some 500 feet from the edge. This offer was not accepted for safety reasons. The ship was unwilling to delay departure another day during which a new effort to produce a hole could have been attempted. It was reluctantly agreed, therefore, to cancel out on the remaining tests at Freeman's Floe and proceed toward Barrow. If other suitable ice, either old polar ice or seasonal ice, was observed near the outer edge of the pack, the ship agreed to stop to allow further tests to be run. During the 36 hours' occupancy of Freeman's Ice Floe, the Floe drifted about 25 miles in a NNW direction (see fig. 2 for plot of track).

A summary or recapitulation of the ice penetration test results is given in figure 14.

The inability by the ship's working party to make suitable holes through the ice was a key factor in the tests. This forced a change in test plan insofar as the method of placing charges into position was concerned, and also forced cancellation of the secondary tests. In retrospect, the reasons for this inability appear to be the unexpected hardness and unusual thickness of the ice. Certainly the failure was not due to lack of determined effort on the part of Lt(jg) Chidsey and his working party.

Working conditions on the ice during the above tests were unpleasant but not severe. The air temperature was relatively mild (in the 20's and 30's) but continuous fresh winds of about 20 knots velocity quickly chilled any exposed skin. The sky was almost continuously overcast, with frequent light snow flurries. Due to the hummocked surface of the ice, with many refrozen melt pools, movement over the ice was somewhat cumbersome. Fiberglas sleds, furnished by the ship, were used for transporting heavy gear on the ice and these occasionally overturned on the hummocks or cracked through the ice on the melt pools. Due to the decision to limit the stay at the floe to 36 hours, those persons involved in the tests were on the ice 27 of these hours in order to accomplish as much of the

SUMMARY OF ICE PENETRATION TEST RESULTS

| Shot No. | Wt. of HBX-3 (lbs) | Standoff Beneath Ice (inches) | Observed Ice Thickness (ft) Min. | Observed Ice Thickness (ft) Max. | Results: Dia. of Pulverized Area (ft) | Results: Dia. of Cracked Area (ft) | Comments |
|---|---|---|---|---|---|---|---|
| 1 | 60 | 47 | 6 | 14 | ~100 | | 50% ice coverage. Fragments to 4'x6' |
| 2 | 35 | 40 | 10 | 16 | ~40 | ~90 | 75% ice coverage. Fragments to 2'x2' |
| 3 | 20 | 37 | 9' 4" at ground zero | | | ~15 | 100% ice coverage. Can be walked on. |

Fig. 14

program as possible. A list of project personnel is given in Appendix F.

In proceeding back to Point Barrow no suitable ice of any sort was found. In fact, wind and sea conditions near the outer fringes of the pack were strong enough to cause break-up of the remaining floes into small fragments. Thus, the secondary tests were not conducted due to lack of opportunity.

During the remainder of the trip the instrumentation and equipment were sorted out for reshipment back to NOL by the STATEN ISLAND after it returned to Seattle. Remaining module charges were offloaded and stored at ARL, Point Barrow, for possible future use. The Ice Press was left at ARL for local use with the agreement that it would be available to NOL on future trips to ARL, or shipped back to NOL upon request. The remaining pipe and other expendable gear were left on the STATEN ISLAND for their use.

Ice characteristics at the test site are given in figures 15 through 17. These were about as expected, except for salinity and the unusual thickness. The salinity was quite low, being on the order of 1200 parts per million near the center of the ice, and tapering off near the top and the bottom. The only apparent explanation is the age of the ice, which must be considerable. Tensile strength (measured according to Dr. Assur's suggested method) averaged about 15 kg/cm$^2$ throughout most of its thickness, being a little less near the (relatively warmer) surface, and a little greater near the bottom. Temperature was nearly constant at 30°F. throughout. In summary, the ice exhibited normal characteristics for quite old polar ice, and was rather strong for summer conditions.

| Sample No. | Depth (ins.) | Sample Temp. (°F.) | Air Temp. (°F.) | Sample Weight (grams) | Load (0.0001") | Actual* Load (lb.) | Strength** of Sample (kg/cm$^2$) | Salinity*** of Sample (ppm) |
|---|---|---|---|---|---|---|---|---|
| A-1 | 12 | 30 | 27 | 285 | 176 | 366 | 12.9 | 420 |
| A-2 | 25 | 30 | 27 | 313 | 213 | 444 | 15.7 | 460 |
| A-3 | 50 | 30 | 27 | 314 | 224 | 467 | 16.5 | 1230 |
| A-4 | 75 | 30 | 27 | 298 | 219 | 456 | 16.1 | 850 |
| A-5 | 100 | 30 | 27 | 322 | 290 | 606 | 21.4 | 260 |
| B-1 | 4 | 30 | 30 | 281 | 155 | 323 | 11.4 | 80 |
| B-2 | 12 | 30 | 30 | 303 | 200 | 417 | 14.7 | 140 |
| B-3 | 18 | 30 | 30 | | | | | 210 |
| B-4 | 40 | 30 | 32 | | 175 | 365 | 12.9 | 1020 |
| B-5 | 60 | 30 | 30 | 307 | 182 | 379 | 13.4 | 920 |
| B-6 | 80 | 30 | 30 | 308 | 185 | 380 | 13.4 | 800 |
| B-7 | 100 | 30 | 30 | 307 | | | | 230 |

Core A was taken in the vicinity of shots #1 and #2.
Core B was taken at ground zero for shot #3.

*From Ring Calibration Chart

**Stress = $\frac{2KP}{\pi DL}$ Stress (Kg/cm$^2$) = $\frac{14.18\,P}{\pi DL} \cdot \frac{0.454}{6.45}$ where P = Actual load in lbs., D = diameter in inches, L = length in inches, K = 7.09 (for psi)

***From titration at ARL, Pt. Barrow, taken at 20°C.

Fig. 15 Ice Core Sample Data Sheet
Dia. of Sample = 3.0" Length of Sample = 3.0" 8/26/61

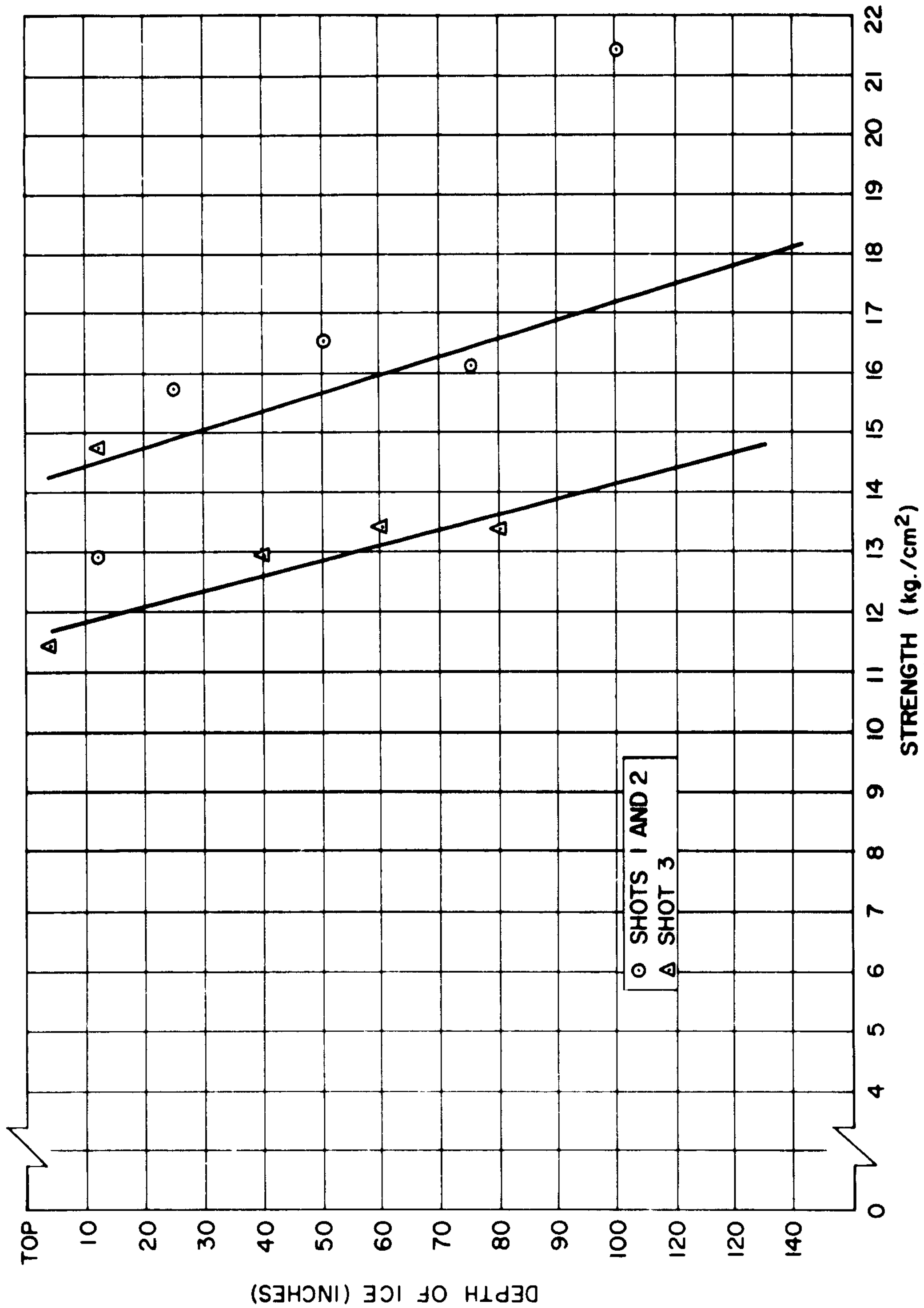



FIG. 16 ICE STRENGTH AT TEST AREAS

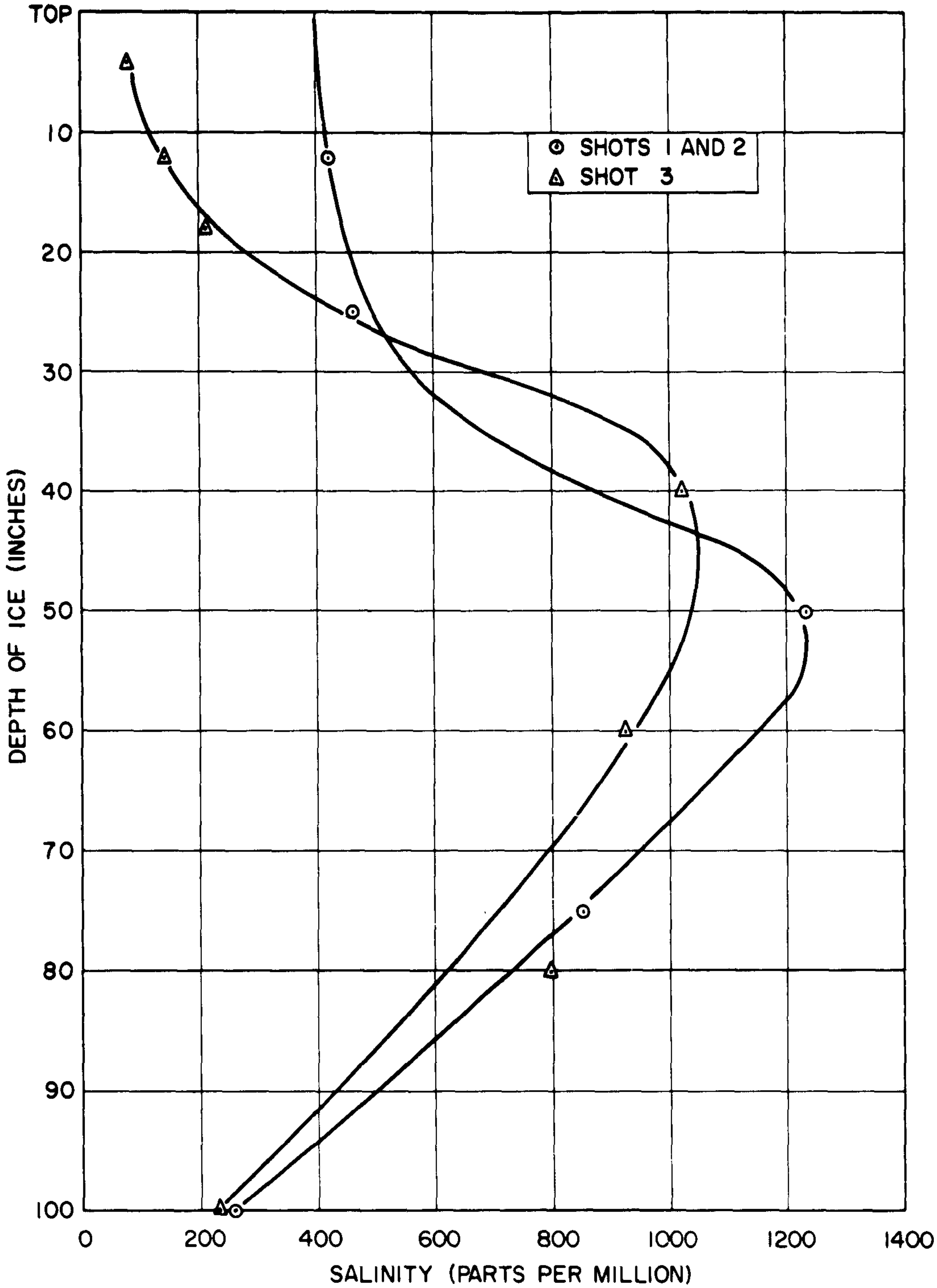



FIG. 17 SALINITY OF ICE IN TEST AREAS

# Chapter 7

## CONCLUSIONS

It is concluded that a 35-pound charge of HBX-3, exploded at the optimum standoff distance under thick polar ice under summertime conditions, will produce a pulverized area on the order of 40 feet in diameter, and a cracked/jumbled area on the order of 90 feet in diameter.

It is emphasized that these data and conclusions apply only to polar ice under summer conditions. Homogeneous samples of ice from nature vary tremendously in their characteristics. The knowledge of these characteristics, particularly tensile strength and elasticity, is still quite sparse. The obvious approach (insofar as explosive effects are concerned) is to select the most resistant sample and collect effects data on this sample; then such data are always on the safe side. But it is not at all clear which is the most resistant ice. Several identifiable types of ice which are of interest in this study, and their relative characteristics are:

| Type of Ice | Seasonal Condition | Relative Salinity | Relative Temperature | Relative Strength |
|---|---|---|---|---|
| Old Polar | Summer | Low ($\lessapprox$ 4 ppt) | warm | mod.high |
| | Winter | Low " | cold/very cold | mod.high |
| Winter (Seasonal) | Summer | Mod.high(~18ppt) | warm | low |
| | Winter | Mod.high " | mod. cold | moderate |
| Quick-Frozen Winter | Summer | Very high (20-25 ppt) | warm | very low |
| (Surfaceable "Skylights") | Winter | Very high (20-25 ppt) | very cold | very high |

Very little information is available on elasticity, an important factor. Equally obscure are the characteristics during transition phases (spring and fall) and characteristics of conglomerate pack (non-homogeneous mixtures of various types).

In summary, natural sea ice exhibits tremendous variations in all its characteristics, including its resistance to explosions. The tests reported herein are limited to one set of conditions (the first line in the above table). This may or may not be the "worst" condition.

# Chapter 8

## RECOMMENDATIONS

It is recommended that if an urgent need for an ice destructor is determined to exist, the design of this ice destructor be based on the data reported herein, even though these data are limited to a single set of ice conditions. When opportunity arises, during the development program, these tests should be repeated under other ice conditions, particularly with old polar ice in midwinter.

It is recommended that further arctic studies related to ASW weapon performance in the Arctic and sub-Arctic be pursued as proposed in reference (g). The recent advent of Soviet nuclear submarines lends urgency to these studies.

It is recommended that theoretical studies of explosion effects on sea ice be extended to include typical ice in the Arctic or Antarctic. Formulation of theoretical and empirical curves and relationships for predicting explosion effects on sea ice should be related to ice variables until sufficient knowledge is at hand to permit reliable predictions of explosion effects to be made under all expected conditions of sea ice.

## REFERENCES

(a) USS SARGO Conf "Report of January-February 1960 Arctic Cruise" (encl (1) to SSN583/3120 Ser 012 to CNO, 3 Mar 1960)
(b) USS SEADRAGON Conf "Report of August-September 1960 Arctic Cruise (SUBICEX 3-60)" (encl (1) to SSN584/3120 Ser 064 to CNO, 14 Sep 1960)
(c) NOL Conf Ltr 3900 Ser 02046 to BuWeps, 13 Jun 1961
(d) "Effectiveness of Explosives in Breaking Clearings in Sea Ice," by R. M. Barash, 15 Mar 1960 (NOLTN-4866)
(e) "Operation ICESKATE: Explosive Tests Under Ice," by D. J. Torpy, 5 Apr 1960 (NOLTN-4912)
(f) "Improved Explosive for Ice-Breaking," Conf., by R. M. Barash, 16 Jan 1961 (NOLTN-5119)
(g) NOL ltr 8550 Ser 1796 to ONR, 23 Mar 1961
(h) ONR ltr ONR:414:MEB:maj to NOL, 29 Jun 1961
(i) ONR Conf Ltr ONR:414:MEB:maj Ser 0983 to COMALSEAFRON, 13 Jun 1961
(j) COMSUBLANT ltr N4/9498 to BuWeps, 24 May 1960
(k) COMSUBLANT ltr 42/01000 to BuWeps, 14 Oct 1960
(l) "Composition of Sea Ice and Its Tensile Strength," by Dr. A. Assur (CRREL) (from National Academy of Sciences-National Research Council Publication 598, "Arctic Sea Ice"), 1958

# APPENDIX A

## Test Plan
18 July 1961

PURPOSE

These tests are for the purpose of obtaining basic data on the effects of underwater explosions on thick sea ice. No data of this type are known to be available, except from a series of three tests that were made from the USS STATEN ISLAND in the Bering Sea during the winter of 1959-1960 in relatively thin sea ice. The data are needed for the design and development of components and systems to meet Operations Requirement SW-001102(REU) "Submarine Under-Ice Operational Requirement," and also to meet the requests made by COMSUBLANT in Serial N4/9498 of 24 May 1960 and Serial 42/01000 of 14 October 1960.

MATERIAL AND SERVICES REQUIRED

A total of 33 explosive charge modular units varying in size from 2 pounds to 200 pounds will be supplied by NOL. By bolting various units together at the test site, a series of some 14 test charges, containing explosive weights from 2 pounds to 1300 pounds, are then available. A selection of six to ten of these test charges will be used based on the ice thickness found to be available for the test. In addition, electrical cable, batteries, buoyancy cans, ten arming devices, and the necessary associated gear will be furnished by NOL. Instrumentation, including three movie cameras and film will be supplied by NOL. A list of all material furnished by NOL is attached. It is requested that the Icebreaker furnish one cameraman to direct the photographic coverage; one or more assistant cameramen, if available, to operate the other two movie cameras and one view camera (black and white); and the services of a helicopter, if available, for air photographic coverage. In addition to these services, it is requested that the Icebreaker furnish structural wood and tackle to assemble an A-frame on the site (if needed for handling the largest charges); photographic markers for marking the explosion area; a view camera and film (for still photo coverage by one of the above assistant cameramen). If Eskimo laborers are not embarked, it is requested that the Icebreaker furnish chain saws, pickaxes, etc., together with the necessary manpower, to cut from three to eight holes through thick (6 to 12 feet) ice, and miscellaneous assistance from the ship's company at the test site as needed to aid in the handling of the charges and gear.

TEST FACILITIES AND CONDITIONS

The prime requirement for these tests is thick sea ice (6 to 12 feet thick) in a more-or-less homogeneous mass at least 500 feet in minimum lateral dimension. The water depth should be at least 100 feet. The vessel should be able to operate near enough to this mass to allow the test charges (maximum weight of any unit component--250 pounds) to be unloaded and carried to the test site. The vessel must be able to move a safe distance away from the explosion and return (1000 yards from the 1300-pound charge). If the ice floe is small, adjacent floes must be available so as to allow the test party to move to a safe distance, about 1000 feet, from the 1300-pound charge. It is preferable that the weather be reasonably calm and that the light/visibility be good for the sake of photographic coverage, including helicopter coverage. The current (or relative ice/water motion) should be low, preferably under 1/2-knot.

TEST METHOD

When the conditions outlined in the above paragraph are located, the explosive shots will be fired according to the following plan (modified as necessary for local conditions and problems):

1. Select a location for the explosion test. The choice and sequence of charges should be selected from figure A-1, which also specifies the standoff distance and (by multiplying the standoff distance by 25) the minimum distance from the hole or ice edge to the charge. In selecting the charge location, consideration should be given to the current (or relative ice/water motion) and, if the floe is small, to the maximum utilization of the ice area for other explosion tests. At the same time the location of the access hole should be selected.

2. Dig a hole completely through the ice at the access hole location, using chain saws and any other available tools. The hole should have tapered sides and a clear diameter at the bottom of about 2-1/2 to 3 feet. The upper ice edge and the opposite lower edge should be trimmed so that pipe can be inserted toward the test location at about a 30° angle with the horizontal. Necessary observations of ice strength, salinity and temperature should be taken at this time. Temperature should be rechecked just before the test if a significant change occurs.

3. Check the specific gravity of sea water at the hole by submerging one section of pipe into the hole. A safety retaining line and a 15-pound (in water) weight should be attached to the pipe. With a hand scale the weight of the pipe-weight

assembly in water should be measured. From this the buoyancy of the pipe section should be calculated and the necessary weights selected to provide an overall buoyancy for each pipe section of +1 to +2 pounds.

4. Using the curves, figure A-1, select the first charge to be fired and rig this with arming device and cable for firing. Select a buoyancy can that will provide about five pounds buoyancy for the small charge assemblies, scaling up to about 25 pounds for the larger charge assemblies. Attach this to the charge with nylon line, allowing the proper standoff distance ($\sqrt[3]{W}$ ft.). Select a compensating weight to neutralize this buoyancy. Attach the charge-buoyancy can and the weight independently to the release device at the end of the first pipe section. The overall buoyancy of the first section, fully rigged, should be about +2 pounds.

5. Insert the first section in the hole (down current) pointed down at about 30° angle and in azimuth toward the test point. One electrical cable and one nylon (or wire) release cable should trail back from the end of the pipe. The release cable should be taped lightly to the pipe once each section. It is expected that the assistance of a UDT swimmer will be utilized for this process.

6. Attach a second section of pipe, taking care that the pipe in the water is never rotated (a stripe or other marker will be used to show this). Tape the release cable lightly to the section once. Repeat this process for as many sections as are necessary for the hole-effect separation of 25 $\sqrt[3]{W}$ ft. minimum.

7. When the pipe is finally in place, but just before pushing the end through the hole, attach a pipe safety retaining line, and take bearings along the pipe to establish the explosion point as closely as possible. Use a tape measure to set off the horizontal distance. Finally, push the pipe end through the hole and have one of the UDT swimmers pull the release line. The entire pipe assembly (which is slightly buoyant) should then be either retrieved through the hole, or pulled back under the ice in the opposite direction until the forward end appears. Check to see that the charge-float assembly and the weight have released properly.

NOTE: If this plan for placing the charge in position proves to be unworkable or unduly difficult, it is intended that the UDT swimmers will (as a back-up plan) place the charges in position.

8. Using a low-current ohmmeter, check the arming motor circuit. Arrange camera coverage, including helicopter, per plan (Appendix B). Set up markers around "ground zero." Clear the area, stringing electrical cable to a safe firing location (Appendix B).

9. In accordance with detailed local plan and the parameters of Appendix B, arm the arming device, monitoring motor switch closure with a Simpson ohmmeter, and closure of the detonator circuit with a low-current ohmmeter. When all is in readiness, and in accordance with local plan, detonate the charge.

10. Based on the results of the first test, select the next charge size, figure A-1, and repeat the test. A minimum of three and a maximum of about six "small" charges probably will be fired in this series. Finally, fire one 630-pound charge and one 1300-pound charge while they are hanging in the water directly beneath the hole in the ice at the required standoff distance.

DATA DESIRED

1. The following ice data should be taken at each test site (temperature and strength measurements should be taken immediately after the hole is cut, and again, if necessary, on an ice core sample just before or after a shot). In each case data are desired for a depth profile.

a. Ice Strength. Samples should be taken with the coring auger, from selected positions along the side of the hole, or from a coring hole. At least three samples should be measured, if practicable, at each depth, and the results averaged.

b. Salinity. Ice samples should be taken and placed in sample bottles at similar locations in the test hole. The salinity can be measured roughly by hydrometer after the ice has melted, but the samples should be labelled and retained for more precise measurements later. Samples of the sea water immediately beneath the ice also should be taken.

c. Temperature. Measurements for temperature profiles should be read at the time of the test and immediately after the ice has been exposed. Water temperature also should be taken.

d. Ice Thickness--at the test location.

2. Relative water current.

3. Movie coverage of each explosion, using at least two cameras, one on the surface and one in the helicopter.

4. Black and white still photographs of the area after each shot.

5. Black and white still photographs of the test steps.

6. Air temperature and meteorological conditions.

7. Water depth.

8. Measurements of cracks developed as a result of the explosion.

9. General description of explosion effects.

MATERIAL FOR UNDER-ICE EXPLOSION TESTS

To be shipped from NOL to NWP/Yorktown for explosive loading by 15 July, thence to Seattle to arrive at STATEN ISLAND by 9 August:

| | |
|---|---|
| 10 | 200 pound containers - aluminum |
| 3 | 100 pound containers - aluminum |
| 3 | 50 pound containers - aluminum |
| 7 | 30 pound containers - aluminum |
| 3 | 10 pound containers - aluminum |
| 3 | 5 pound cups - aluminum with 1/16-inch cover plates |
| 4 | 2 pound cups - aluminum with 1/16-inch cover plates |
| 16 | Large filling hole covers and gaskets |
| 10 | Small filling hole covers and gaskets |

The above will be in shipping containers suitable for reshipment to Seattle.

To be shipped by NOL to Yorktown 21 July, thence to STATEN ISLAND by 9 August:

Charge Parts

| | |
|---|---|
| 10 | Arming Devices |
| 13 | Arming Device Casings, steel |
| 13 | Arming Device Casing Covers, steel |
| 3 | 5 pound cup casings, steel |
| 4 | 2 pound cup casings, steel |
| 4 | Casing end cover plates, steel |
| 30 | 4-1/2 x 1/8 "O" rings |
| 200 | 3/8 x 1-1/2 Allen Head Cap Screws |
| 200 | 3/8 x 7/8 Allen Head Cap Screws |
| 200 | 3/8 Nuts |
| 200 | 3/8 Lock Washers |
| 36 | 3/8-16 Eye Bolts, 1" long |
| 2860 | feet 5-conductor electrical cable |
| 1000 | feet 2-conductor electrical cable |
| 3 | 5,000 ft. rolls - 4,000-pound nylon line |
| 2 | 1,000 ft. rolls - 1200-pound nylon line |
| 400 | feet 6061T6 aluminum pipe - 20 ft. sections |
| 20 | couplings for aluminum pipe, aluminum |
| | Misc. buoyancy cans - tools packed in these |
| | Misc. weights, various sizes, also in cans |
| 3 | Release Devices |
| 12 | Arming Device Boosters, tetryl leads |
| 12 | Explosive Fittings for Arming Devices |
| 12 | 1-pound TNT blocks |
| 12 | Blasting Caps |

Instrumentation

| | |
|---|---|
| 3 | 16 mm Movie Cameras (to be operated by S1 photographer) |
| 1 | Polaroid Camera |
| 1 | Coring Auger |
| 5 | Thermometers - bimetallic with probes |
| 1 | Hydrometer (for salinity measurements) |
| 24 | Sample size bottles for water & ice samples, 8 oz. |
| 144 | Sample size bottles for water & ice samples, 4 oz. |
| 1 | Box of labels |
| 1 | Ice strength gage |

Tools and Hard Instruments

| | |
|---|---|
| 2 | Complete Tool Kits |
| 1 | Simpson VOM |
| 2 | Sets batteries for arming and firing<br>Set of 3 - 6 volt Hotshots |
| 2 | 22-1/2 or 45 volt batteries |
| 1 | Demolition Box - spin type |
| 1 | Mk 32 Test Set |

Miscellaneous

| | |
|---|---|
| 2 | Doz. pr. white cotton gloves |
| 1000 | ft. piano wire<br>("A" frame and site markers from STATEN ISLAND) |

1 DETERMINE TEST CONDITION FROM UPPER CHART.

2 ON THE LOWER GRAPH, READ ALONG LINE REPRESENTING AVAILABLE ICE THICKNESS. CHOOSE CHARGE WEIGHT AS CLOSE AS POSSIBLE TO MID-POINT (LOGARITHMIC) OF DESIRED TEST-CONDITION INTERVAL.

3 DETERMINE CHARGE STANDOFF AS A FUNCTION OF CHARGE WEIGHT, FROM LOWER GRAPH

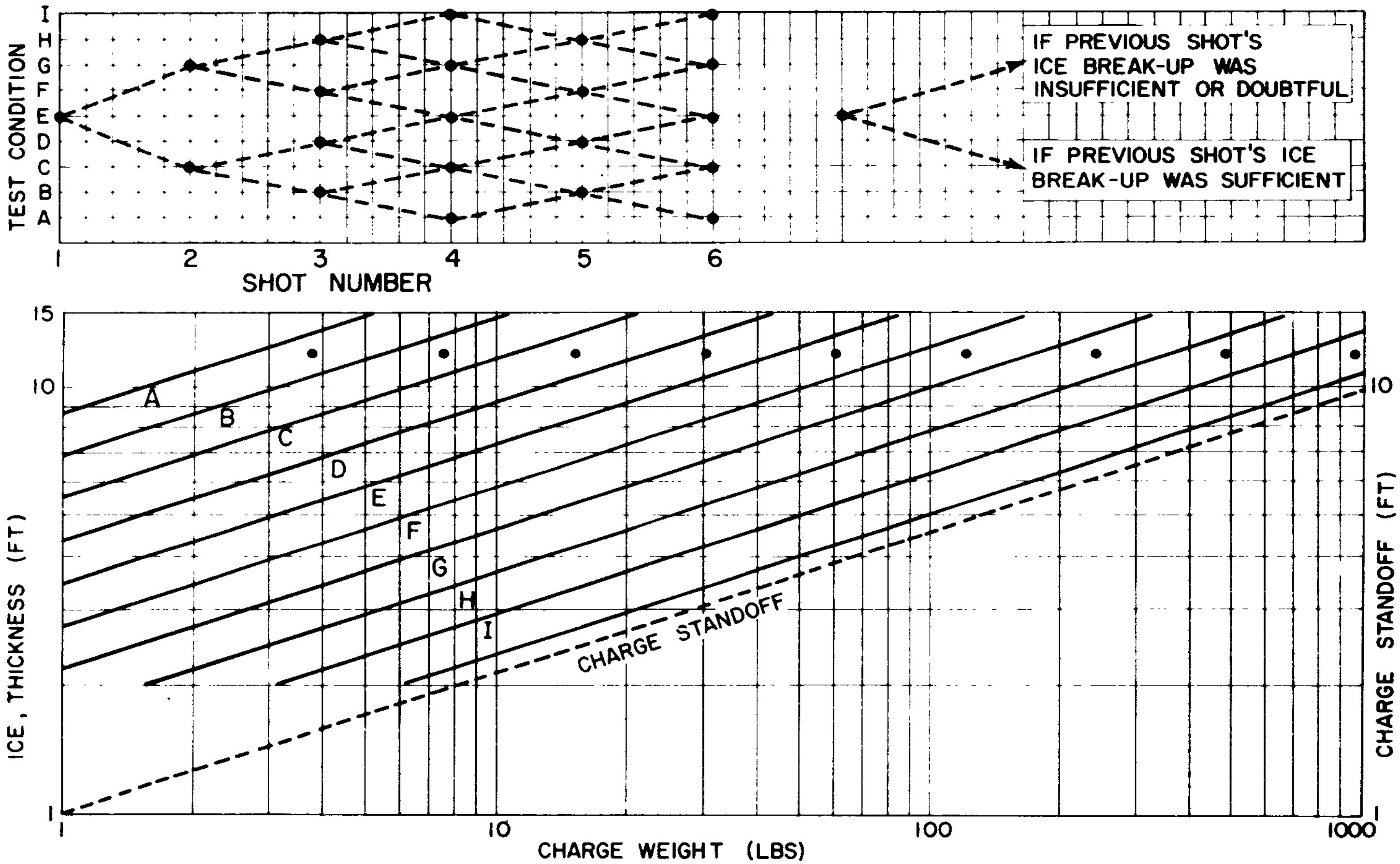



FIG. A-1 ORDER OF TESTS

# APPENDIX B

## NOTES ON TEST PARAMETERS

1. Bubble diameter, HBX-3: $\sim 10\sqrt[3]{W}$ ft.

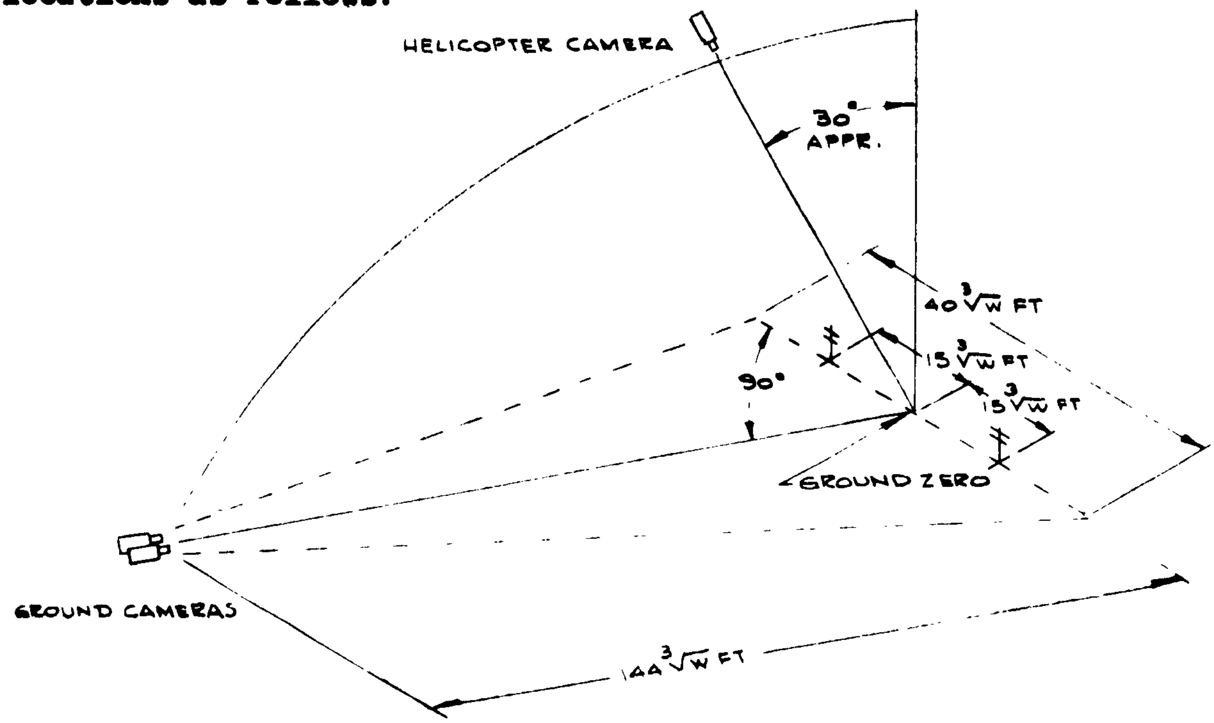
2. Extent of test area should be such that distance from shot to ice edge or major anomaly is not less than $25\sqrt[3]{W}$ ft., preferably $50\sqrt[3]{W}$ ft. (five bubble diameters).

3. Water depth should be at least $20\sqrt[3]{W}$ ft. (two bubble diameters).

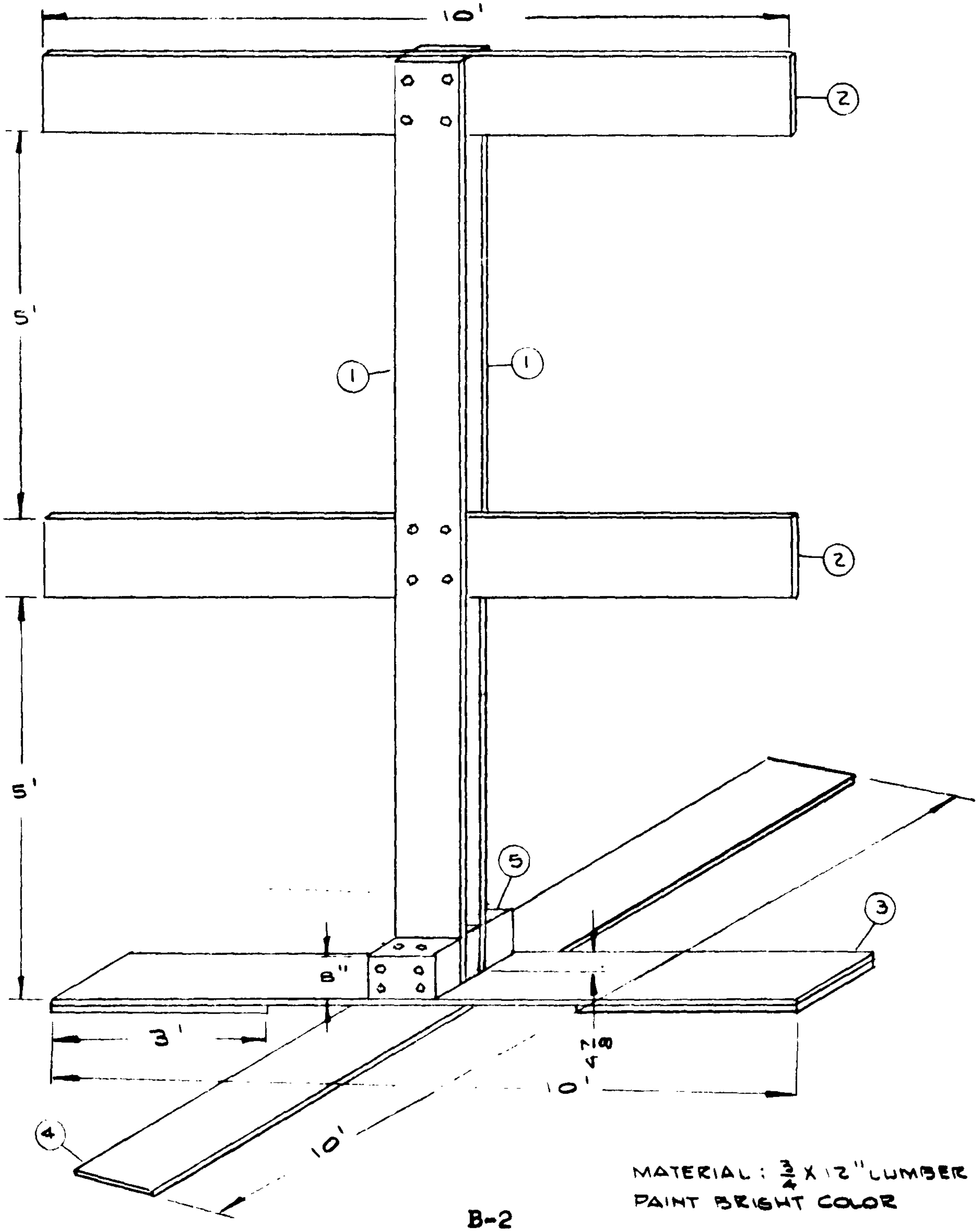
4. Charge standoff beneath the ice should be $\sqrt[3]{W}$ ft. for optimum effect (based on previous tests).

5. Ship safe distance for negligible shock damage is sometimes given as $6\sqrt{W}$ ft. (Note: square root). Because of ship's age and desired additional safety factor, a distance at least ten times this should be used.

6. Motion picture photography. Two 16 mm ground cameras and one 16 mm helicopter camera will cover each shot. One ground camera should be operated at 64 fps and the other at 16 fps. The helicopter camera should run at 16 fps. Two photographic markers are to be set up, one on each side of ground zero, with locations as follows:



The two photographic markers should be made to the following dimensions to provide usable photographic scaling factors:



# APPENDIX C

## Feasibility Study and Test of Pipe Placement System

A test was conducted at Solomons, Maryland on 7 July 1961. Those participating from FS-4 were: D. M. Leslie, V. G. Costley, C. A. Nelson, and W. H. Gulledge. The tests were conducted on a raft tied to a barge anchored in the mouth of the Patuxent River. The raft had a hole through the middle, which was used to simulate a hole in thick Polar ice.

The object of the tests was to determine if some 100 - 150 feet of 2-inch aluminum pipe could be successfully assembled and pushed through a hole in the ice with an explosive charge on the end to place this charge back under the ice. Several things were to be determined about the system:

1. Could the 20-foot sections be assembled as they were being put down through the hole?

2. Would the bending moment on the pipe at the edge of the hole due to the pipe's buoyancy in the water be enough to bend the pipe?

3. Would a mechanical release for holding the charge to the pipe until placement under the ice be successfully actuated?

4. Were threaded couplings the best way to put the pipe sections together?

5. What would assembly handling be like when there was a current running beneath the raft?

The first step of the test was to start assembling the pipe and pushing it through the hole with no weights attached to overcome some of its buoyancy. Galvanized iron couplings were used with the aluminum pipe. A compound made by the General Electric Company (Electrical Insulating and Sealing Compound MIL-1-8660) was used as a lubricant and joint sealer. Assembly was quite easily accomplished with some seven or eight men participating. When three 20-foot lengths had been put through the hole, a rough approximation of the bending moment on the pipe where it was against the bottom edge of the hole was measured. It was found to be 600 ft-lbs. A fourth length was then added and shoved down. At this point the far end of the pipe rose to the surface some 70 feet beyond the raft. The

pipe was bowed down into the water from the raft and then back up to the surface. It stayed this way for a few seconds and suddenly broke at the third coupling. The section was retrieved before it sank, and it was noted that it had broken at a coupling when the threads stripped and pulled out of the coupling.

For the second test, 26 pounds of lead were attached to the end of the pipe that was inserted into the water first. It had been estimated that 100 feet of the pipe would have a buoyancy of 36 pounds. The effect of this lead weight was to make the first two sections more difficult to hold onto when being assembled. When 80 feet of pipe had been assembled, the moment was again checked and found to be 360 ft-lbs. After 100 feet had been assembled, the close end was capped and the entire pipe pushed through the hole so that it was laying in the water. The first 50 feet lay about flat on the surface, then the remainder bent down into the water to a depth of 17 feet where the 26 pounds of lead was attached. It was felt this was unsatisfactory because a charge attached at that point would be too far below the ice.

For the third and final test, a buoyancy can was rigged to have about three pounds positive buoyancy and attached to the release device on the end of the first pipe section. This was first tested to be sure it would float. Then as the pipe was once again assembled and put through the hole, a weight of from five to eight pounds was attached at each coupling and at the release device to reduce the pipe's buoyancy. In this way the weight would be distributed along the pipe and not pull one end way down. A nylon line was also taped lightly to the pipe from the release device. The pipe went down quite easily with this system except that a current of about 1/2-knot which was running now due to the tide carried the pipe around under the raft as it was being inserted. When the pipe was all in (100 feet), the release was pulled but the buoyancy can never appeared. It had been either deformed and made to leak due to its depth at one point (perhaps 70 feet), or been carried way out under water by the tide.

These are the conclusions about the points which were of interest:

1. The sections could be assembled with a minimum of trouble provided enough personnel was available to help.

2. The pipe would stand the bending moment applied to it. The pipe, in fact, was found to be quite flexible.

3. A release could be actuated, although a more positive system of ejection from the release should be developed.

4. The threaded couplings were the weakest part of the system. From the standpoint of speed and strength, another quick-connect system should be developed.

5. A current makes assembly somewhat more troublesome, but not prohibitively.

The strength of the pipe in bending moment was calculated as follows:

2" Extra Heavy Aluminum Pipe

Material - 6061 T6
Yield - 35,000 psi
OD - 2.375
ID - 1.939

$$Z = \frac{I}{y} = 0.098 \frac{D^4 - d^4}{D}$$

$$= 0.098 \frac{(2.375)^4 - (1.939)^4}{2.375}$$

$$= 0.098 \frac{31.8 - 14.1}{2.375}$$

$$= 0.73 \text{ in.}^4$$

$$M = SZ$$

$$= (35{,}000)\ (.73)$$

$$= 25{,}600 \text{ in-lbs.}$$

$$= 2{,}130 \text{ ft-lbs.}$$

# APPENDIX D

## Description of Charges for Point Barrow Ice Tests

The Arctic test charges have been designed in modular form. The assembled charges will be in the following sizes: 2, 4, 7, 10, 15, 20, 30, 45, 70, 100, 150, 250, 600, and 1300 pounds of explosive. In order to provide charges in the larger sizes and still have units which can be handled easily on the Arctic ice, seven modules were designed that could be bolted together to form these assembled charges. The module explosive weights are 2, 5, 10, 30, 50, 100, and 200 pounds. The approximate total weights of the modules are 5, 12, 18, 41, 74, 128, and 244 pounds. There will be one arming device for each assembled charge, weighing about five pounds.

It should be noted that there are three methods used to bolt the pieces together, depending on the particular situation:

1. Outside Rings. The 200-, 100-, 50-, and 30-pound charges have a ring on both ends with eight drilled holes, while the 10-pound charge has a single larger ring on one end. These rings are bolted together, one unit to another, with 3/8 x 1-1/2 bolts when the units are the same diameter. It should be noted that the filling hole, which extends from the top of the 200-, 100-, and 50-pound charges of one unit, fits into the arming device socket in the bottom of the next unit so that the bolting rings come together.

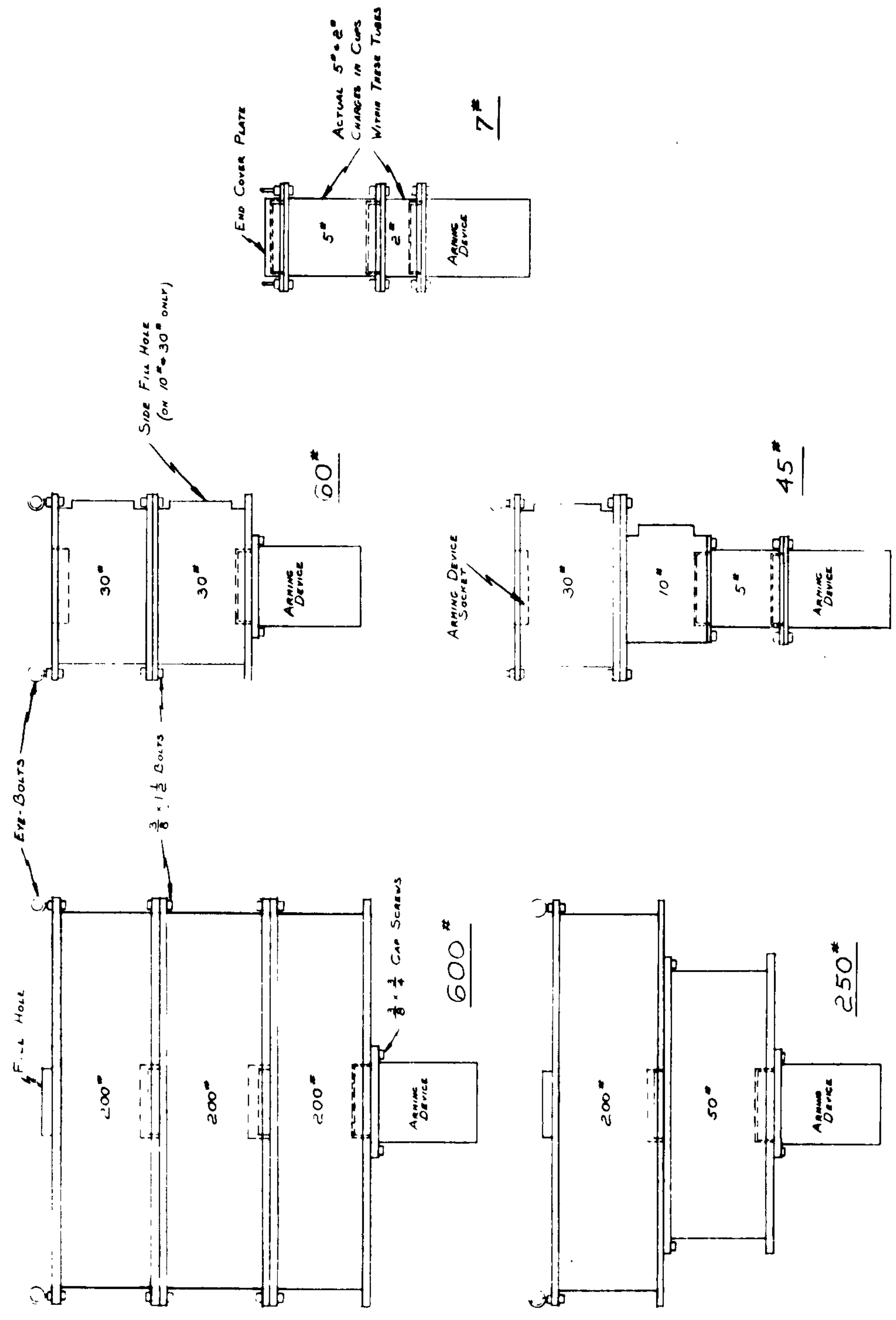
2. Outside Rings and Cap Screws. When a small diameter unit is to be bolted to a larger diameter unit, the outside ring on the small unit is placed on the larger unit so that the tapped holes in the bottom of the larger unit line up with the drilled holes in the ring. 3/8 x 3/4 cap screws are then inserted to hold the pieces together. The same care should be taken to fit filling holes into arming device sockets on the 200-, 100-, and 50-pound charges.

3. Open Tubes into Arming Device Socket. Normally the arming device will be put into the socket in the bottom of the lowermost unit in the charge, except when the 2-pound and 5-pound charges are being used. In that case the short open tube and/or the long open tube are first inserted in this socket. The 2-pound and/or 5-pound charge cups are slipped into this open tube and then the arming device is put on the end of this tube up against the small charges.

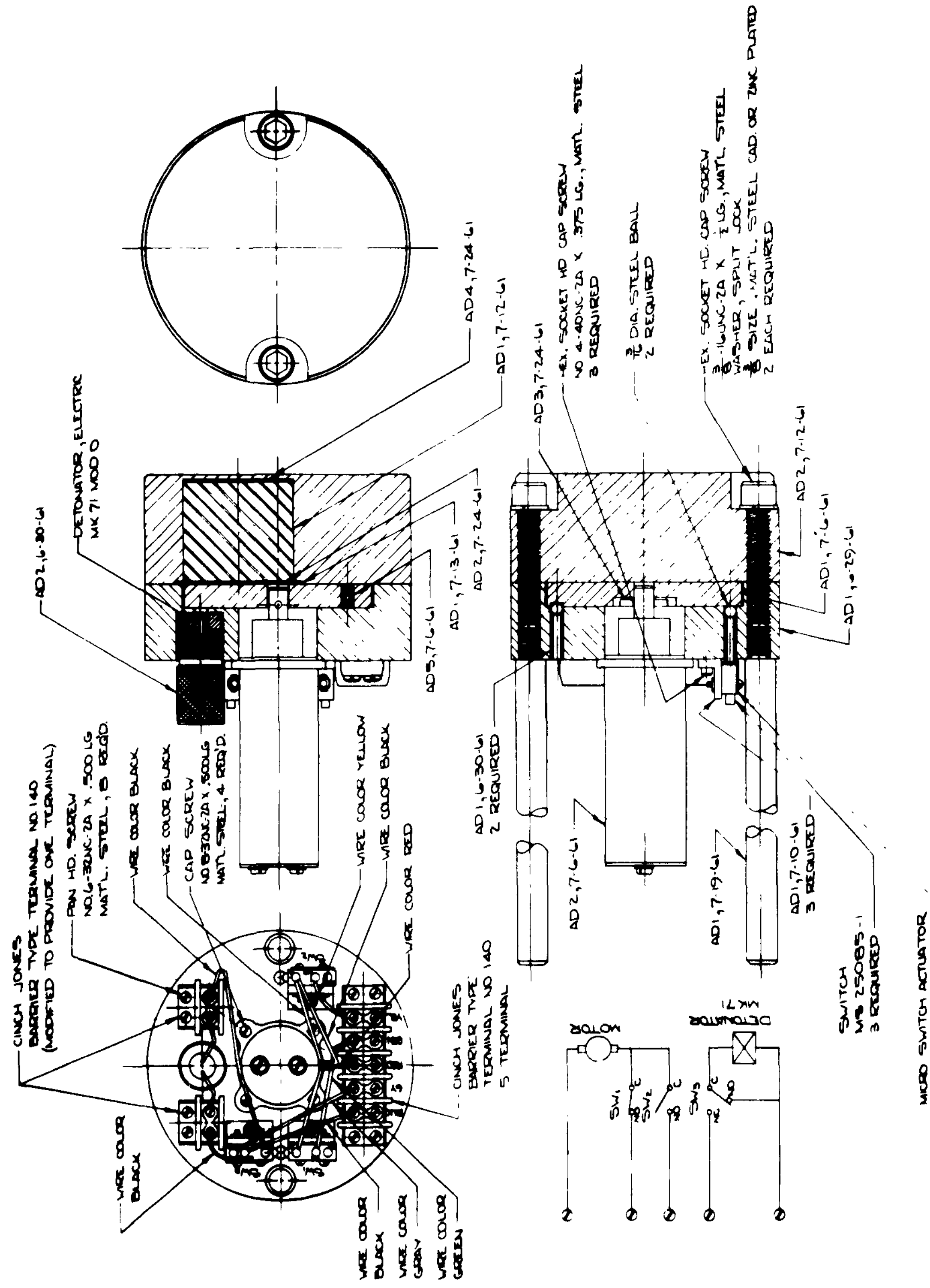
These open tubes are assembled into the sockets by slipping the 4-1/2 x 1/8 "O" ring into the groove on the male end and inserting into the socket with the four drilled holes in the flange lined up with the tapped holes in the unit with the socket. 3/8 x 3/4 cap screws are then put in to hold the tube on. The tubes have been made 1/8-inch shorter than the cup charges to permit tight assembly, so the flanges should not be tightened down until the arming device is inserted in the same manner.

After the charge is bolted together, four eye-bolts are positioned 90° apart in the uppermost ring of the charge for attaching the suspension line. Buoyancy chambers and suspension lines of the correct length for proper stand-off, prepared previous to going on the ice, will be attached to these eye-bolts.

A sketch of typical charge assemblies is attached for convenience.




SKETCH D-1 TYPICAL TEST CHARGE ASSEMBLIES



SKETCH E-1 ARMING DEVICE

# APPENDIX F

## Project Personnel List

### NOL TEST PARTY IN THE ARCTIC

D. M. Leslie
C. A. Nelson
W. E. Burke
T. B. Heathcote
H. C. Axtell
W. H. Gulledge

### ASSISTING ICE EXPERT

Chia-Yao Yuan (Arctic Research Lab., Univ. of Alaska)

### SHIP'S KEY PERSONNEL

Cdr. W. L. Larson, USN (Captain)
Lt(jg) J. F. Chidsey, USN (in charge of Working Party on the ice)

### UNDERWATER DEMOLITION TEAM UDT-12

Lt(jg) Clayton B. Freeman, USNR, Officer-In-Charge
Dever L. Cunningham, QM-2
Barry W. Enoch, GM-2
Billy W. Machem, RD2-P1
Ronald E. Saillant, SF-1
Thomas H. Spence, BMC

### OTHER NOL PERSONNEL CONTRIBUTING TO PROJECT

D. Adams (Instrumentation)
J. S. Allulis (Ordnance Locator investigation)
R. M. Barash (Charges, photographic instrumentation)
V. G. Costley (Pipe placement, charge design, etc.)
J. B. Dempsey (Photographic instrumentation)
S. G. Dowgallow (Charge containers, pipe placement)
V. G. Johnson (Charge containers, pipe placement)
C. C. Vogt (Planning)
S. Wolf (Ice measurements)
D. J. Torpy (Photographic instrumentation)

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| Arctic Research Laboratory<br>Point Barrow, Alaska<br>Attn: Dr. Hal Peyton | |
| University of Alaska, Geophysical Institute<br>College, Alaska<br>Attn: Dr. C. T. Elvey | |
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(NOL technical report 61-146)
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Several small charges of high explosive were fired under old polar ice in the Arctic Ocean to study their effects on ice. At the test site the ice varied from 8 feet to about 16 feet in thickness, and was characterized by low salinity, relatively warm temperature, and moderately high tensile strength. It was concluded that a 35-pound charge of HBX-3 exploded at optimum standoff distance beneath this type of ice will pulverize an area at least 40 feet in diameter, and will crack the ice extensively in an area about 90 feet in diameter.

Abstract card is confidential

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1. Ice - Explosion effects
2. Explosions, Underwater
3. Explosives, High
4. HBX-3
5. Arctic Ocean

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II. Leslie, Donald M.
III. Nelson, Carl A., jt. author
IV. Project

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